Three Essays on the Interbank Market

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The Faculty of Business, Economics and Informatics of the University of Zurich hereby authorizes the printing of this dissertation, without indicating an opinion of the views expressed in the work.

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Part I

Dissertation Overview

Dissertation Overview

The interbank market is important for banks to obtain liquidity. From the recent financial crisis it is now clear that access to liquidity is vital for a bank's business. There are two main components of the interbank market: the unsecured and the secured market. The latter is commonly called repo market; repo is short for repurchase agreement. In a repurchase agreement, a security is sold at a fixed price with a promise to buy it back at this price at the end of the contract including the repo rate, the interest rate applied to this transaction. The security serves as collateral, if the cash taker defaults. There are two types of repo transactions, general collateral (GC) and special. The motive for trading GC repo is liquidity, whereas for trading special repo the specific security. All three papers included in this dissertation use data provided by Eurex Repo, who offers a platform for electronic repo trading. The first paper, joint with Kjell G. Nyborg, links rates in the unsecured and the repo market, and develops a theory on their relationship, which is supported by empirical tests. In the second paper, the drivers of the special repo market are analyzed, so that the reaction of this market to external influences can be understood better. The third paper shows that there are allocational inefficiencies in the distribution of liquidity in the interbank market (unsecured and GC repo) due to institutional factors and frictions, which strengthen during the crisis, and do not disappear despite the provision of excess liquidity by the Eurosystem. Each paper forms one chapter of my dissertation, and are now introduced in more detail.

The first chapter *Repo Rates and the Collateral Spread Puzzle: Theory and Evidence*, which is written in collaboration with Kjell G. Nyborg, develops a theory on the collateral spread, unsecured interbank rate – repo rate. The puzzle is that this is frequently negative. We develop a theory of repos motivated by the need to generate liquidity. Players are risk averse (but risk neutrality is also covered). Trading in the security cash market is an alternative to repo. Unsecured borrowing constraints generate a constrained-arbitrage relation between the repo rate, the illiquidity and risk-adjusted cash market rate of return, and the unsecured rate. The repo rate may rise above the unsecured rate if the cash market adjusted rate does so too. Thus, negative collateral spreads may be a symptom of especially low unsecured rates or depressed securities prices. Collateral spreads increase in haircuts and decrease in volatility. The theory is tested using data from Eurex repo. The findings are supportive. Finally, we use the theory to provide a narrative of the evolution of collateral spreads in the euro area over time.

In the second chapter *The German Electronic Special Repo Market: Activity and Prices*, I analyze the drivers of the electronic special repo market in Germany, Eurex Repo. Volumes, i.e. activity, in the special repo market are captured by the number of trades per trading day and traded volume. Prices are given by the special repo rate and specialness. The lower the special repo rate, and the higher the specialness, the more expensive is the security in the special repo market. I find that one important determinant for a bond trading special is its issue size. The larger the issue size is, the larger the number of trades per trading day and the respective traded volume. The bond itself is cheaper, i.e. specialness is lower. Furthermore, trading in the special repo market is strongly impacted by the European Central Bank's policy measures and financial market uncertainty. The latter, measured by the VSTOXX, leads to lower activity, and higher specialness, indicating a higher premium of trading in the special repo market. ECB excess liquidity and asset purchase programmes tend to decrease activity in special repo. The cost of trading special repo usually falls under the asset purchase programmes, which can be due to restored market conditions and/or market segmentation. The ECB's switch to a negative policy rate, the reference rate in repo, impacts special repo trades, as negative rates provide a disadvantage to the cash provider/security borrower in the transaction. He obtains a lower cash balance at the end of the transaction as compared to the initially provided cash loan. This reduces the attractiveness of special repo.

In the third chapter *Frictions in the Interbank Market: Evidence from Volumes*, I study the impact of frictions and institutional factors on the (optimal) liquidity allocation in the interbank market. The frictions identified (squeezing, credit risk, uncertainty and link to other financial markets) affect each segment of the interbank market differently. In addition to calendar day effects in interbank market volumes due to institutional requirements, these frictions amplify the segmentation of the interbank market, thus inhibiting the efficient redistribution of liquidity within this market. The analysis combines data on the overnight unsecured and repo market with data on the use of the standing facilities at the Eurosystem. Before Lehman, I find evidence for allocational inefficiencies in the interbank market due to frictions. During the crisis, credit risk is the main factor that changes trading activity in the interbank market. Moreover, there is a link to other asset markets impacting the distribution of liquidity. Higher expected stock market volatility leads to precautionary liquidity hoarding and a higher demand for repo transactions. Finally, the results suggest that frictions persist in the course of the crisis despite the extensive measures taken by the Eurosystem.

My dissertation adds to the understanding of how the interbank market functions, in particular the repo market. An analysis of the impact of frictions on both the unsecured and secured interbank market in Europe has not been done before. Bindseil, Nyborg, and Strebulaev (2009) show the existence of allocational inefficiencies before the start of the financial crisis, but not in the presence of high credit risk and Eurosystem strong liquidity supply. Thus, I add to Mancini, Ranaldo, and Wrampelmeyer (2016)'s analysis of the repo market in Europe by exploring in detail the impact of frictions and development of allocational inefficiencies. The building stone for special repo is Duffie (1996)'s model, which was confirmed by Jordan and Jordan (1997)'s empirical analysis. Nevertheless, there are no studies that analyze, how external factors, such as Eurosystem unconventional monetary policies, impact supply and demand in the special repo market, as reflected in volumes. My analysis contributes to a better knowledge of how those policies affect specialness, adding to Corradin and Maddaloni (2015)'s and Dufour, Marra, Sangiorgi, and Skinner (2017)'s studies. A theory on GC repo rates does not exist so far, so Prof. Kjell Nyborg and me are the first ones to offer a model on repo rates and the collateral spread. We also indicate those instances, when the repo rate can exceed the unsecured rate. Thus, my dissertation provides many new findings and improves the understanding of the interbank market.

The structure of the dissertation is as follows: My three papers are found in Part II. Part III contains the bibliography and Part IV presents my curriculum vitae.

Part II

Research Papers

1 Repo Rates and the Collateral Spread Puzzle: Theory and Evidence

Joint with Kjell G. Nyborg

1.1 Introduction

Repurchase agreements (repos) are often characterised as being, in effect, a type of collateralised loan (Duffie, 1996). Repo rates would therefore be expected to be lower than unsecured rates, which indeed they typically are. However, a puzzling feature of the market for liquidity is that repo rates shoot above unsecured rates from time to time, sometimes even for extended periods. This is illustrated in Figure 1.1. The figure graphs what we call the *collateral spread*, defined as the difference between the unsecured rate and the repo rate. Thus, a negative value of the collateral spread means that the repo rate is higher than the unsecured rate. The figure shows that during the financial crisis, repo rates in the euro area were several basis points above unsecured rates for prolonged periods of time.[1] We can also see that repo rates occasionally went above unsecured rates even prior to the crisis. Over the sample period in Figure 1.1, the collateral spread is negative approximately 25% of the time.

A negative collateral spread is puzzling because repos are typically viewed as reducing credit risk relative to unsecured borrowing. The long periods of negative collateral spreads shown in Figure 1.1 are all the more surprising because the repo rate that we have used is from a central counterparty (CCP), which should eliminate credit risk. In this paper, we seek to understand the puzzle of negative collateral spreads and, more generally, shed light on the behaviour of repo versus unsecured rates.

Improving our understanding of repo and unsecured rates is important for a number of reasons. First, the market for liquidity is central to the financial system, e.g., (Bindseil, Nyborg, and Strebulaev, 2009; Fecht, Nyborg, and Rocholl, 2011; Gorton and Metrick, 2011), among others. Second, the market for liquidity interacts with securities markets, (Brunnermeier and Pedersen, 2009) and frictions in the market for liquidity spill over to the broader financial markets (Nyborg and Östberg, 2014). Third, interbank rates are used

[1] While Figure 1.1 uses overnight rates, the same holds true for longer tenors.

as reference rates in mortgages, various credit agreements, and in derivatives markets. The significance of these rates to society as a whole is emphasized by the public and regulatory outrage at the manipulation of Libor by a number of banks.[2] In the wake of the Libor scandal, the Financial Stability Board (FSB) in Basel and others have called for Libor to be replaced by a repo rate benchmark.[3] This points to the importance of rates set in the market for liquidity, especially in the post-crisis landscape, and Figure 1.1 underscores that we have much to learn about them. In this paper, we first study the relation between repo rates and unsecured rates theoretically and then proceed to empirically test some of the implications of our theory.

As discussed by Duffie (1996), repos are often used as vehicles by cash takers to finance the purchase of the underlying collateral. They can also be driven by the cash provider's objective of obtaining a particular security. Duffie's focus is on such "special repos."

The theory we develop is most relevant for general collateral (GC) repos. These are typically thought of as being driven by the cash taker's want to obtain liquidity. In GC repos, the cash taker (borrower) may deliver one of several securities to the cash provider (lender) from a prescribed basket, or list, of eligible collateral. For example, in the popular GC Pooling ECB basket contract offered by Eurex Repo, which is cleared by a Central Counterparty (CCP), the list of eligible collateral stood at approximately 7,500 ISINs in August 2013. It is the feature of a repo that the underlying collateral is made available to the cash provider that makes a repo different from a plain collateralized loan. This is also a key ingredient in our theory, but for a different reason than in models of special repo rates. In particular, in our model, the cash provider needs the underlying collateral to (partially) finance the reverse repo. To explain this, it is useful to first summarize our basic theoretical framework.

The perspective we take in this paper is that, apart from borrowing unsecured, the alternative to raising liquidity by doing repo is to sell the underlying security in the cash market and buy it back later. We can think of this as a "home-made" repo. This may involve additional transaction costs, for example due to illiquidity. In addition, in the cash market home-made repo, the interest cost of raising the liquidity is a function of the security's future price, which is stochastic. So the relative attractiveness of doing a regular or a home-made repo is a function of the repo rate in comparison to the illiquidity and risk-adjusted cost of engaging in cash market trades.

An important ingredient in our model is that both the cash taker and the cash provider are constrained in the unsecured market. As our model abstracts from credit risk, the

[2] Disputes and court investigations continue long time after the detection of the manipulation (Bloomberg, April 04, 2016, *Five Ex-Barclays traders plead not guilty to Libor manipulation*).

[3] See Financial Times, April 25, 2014, *US regulators urge quick Libor replacement*, retrieved from FT.com on April 29, 2014.

absence of borrowing constraints in the unsecured market would imply that the repo rate would always be equal to the unsecured rate. We abstract from credit risk for both theoretical and empirical reasons. First, from a theoretical perspective, credit risk cannot explain negative collateral spreads. Second, from an empirical perspective, as seen in Figure 1.1, negative collateral spreads are common in overnight CCP repos, where credit risk should not be a concern. The cash provider and taker may face different borrowing constraints. While it may seem "natural" to think of the cash taker to be more constrained, we study both the case that he is and the case that he is not, which adds to the richness of the predictions of our theory.

One often thinks of cash providers in repos as liquidity rich. In some models, this may be also be assumed. In our model, however, one may more appropriately think of the cash provider as an intermediary, or arbitrageur, between players that have liquidity and those that are short and seek it.

Constraints in the unsecured market and the need to trade in the cash market gives rise to a constrained-arbitrage relation between the repo rate, the unsecured rate, and the collateral's cash market adjusted rate of return. The nature of this relation depends on a number of parameters such as the potentially different borrowing constraints of the different players, the haircut in the repo, the players' risk aversion coefficients and the volatility and illiquidity of the underlying collateral. The sign of the collateral spread depends on the relation between the unsecured rate, which we treat as exogenous, and the illiquidity and risk-adjusted cash market rate of return of the underlying security. Roughly speaking, the collateral spread is positive if and only if the cash market rate adjusted rate of return is below that of the unsecured rate.

Thus, collateral spreads can go from the normal positive situation to negative if either (1) the unsecured rate drops sufficiently, or (2) securities prices fall sufficiently, implying an increase in the illiquidity and risk-adjusted security cash market rate of return. Scenario (1) helps explain the spikes seen in Figure 1.1. As is well known, unsecured rates usually spike either up or down at the end of reserve maintenance periods and up at the end of calendar months (Fecht, Nyborg, and Rocholl, 2011; Nautz and Offermanns, 2008; Perez-Quiros and Mendizabal, 2006). This causes a move in the same direction in the collateral spread, since the securities market is not similarly affected by these calendar effects. Scenario (2) helps explain the prolonged periods of negative collateral spreads shown in Figure 1.1 as periods where securities markets were depressed. Further subtleties of the conditions under which positive and negative collateral spreads obtain are elaborated further upon in the body of the paper.

One other result relating to negative collateral spreads we want to point out here is that, as a general rule, negative collateral spreads are only possible if the cash provider is less constrained in the unsecured market than the cash taker.[4] Thus, the fact that collateral spreads are often negative may be viewed as empirical confirmation of the commonly held notion that cash providers are players who have a comparative advantage in the unsecured market. This result arises because of the basic mechanism of a repo with constrained players. If the collateral spread is negative, then it is advantageous to borrow as much as possible in the unsecured market. If the potential cash provider is less constrained than the player that seeks liquidity, then the latter can, essentially, relax her unsecured borrowing constraint by raising funds from the former. If the potential cash provider is more constrained, however, there are no such gains from trade. So in this case, a negative collateral spread would not be consistent with equilibrium.

We use data provided by Eurex Repo to test three predictions of our theory.[5] For all three tests, we use the GC baskets with the most active overnight trading, namely the GC Pooling ECB basket and the GC Pooling Extended basket.[6]

First, we exploit the feature of the unsecured market that it spikes, as discussed above, for reasons largely relating to the central bank's operational framework and end-of-month window-dressing by banks.[7] So these spikes are unrelated to what is happening in the securities markets. Thus, by our arbitrage relation discussed above, the collateral spread will spike in the same direction. The evidence is strongly in support of our theory.

Second, we use an exogenous change to haircuts to test the prediction of our model that the collateral spread is decreasing in the haircut (when the collateral spread is positive). This uses the institutional feature of our data that in the two GC contracts we look at, Eurex, not the counterparties, determines the haircuts. This corresponds to an assumption in our model that haircuts are exogenous. Moreover, Eurex uses the same haircuts as in Eurosystem repos (Mancini, Ranaldo, and Wrampelmeyer, 2016; Nyborg, 2017b), which, as shown by Nyborg (2017b) have historically been updated every three to four years. On September 27, 2013, the ECB announced changes to haircuts in Eurosystem repos as of October 1, 2013. For the most part, haircuts were lowered. We have obtained actual haircuts from Eurex around this time and show that haircuts for the securities in the two baskets we are studying fell on October 2, 2013, consistent with Eurex' policy of using Eurosystem repo hairucts. Our tests show that collateral spreads also fell, as predicted by our theory, after this date.

Third, we examine the effect of volatility on collateral spreads. Our theory predicts that higher volatility should be associated with a lower collateral spread. The intuition

[4]There is one "trivial" exception. See Theorem 2.

[5]Mancini, Ranaldo, and Wrampelmeyer (2016) also use this data, but focus on volume.

[6]See Section 1.4 for details on these and other GC contracts trading on Eurex.

[7]Again, we refer the reader to the body of the paper for further discussion.

for this result is that the higher cash market volatility feeds into a lower repo rate because it becomes more “costly” for a risk averse cash provider to (partially) finance the reverse position through the cash market. To examine this, we study the change in the collateral spread on governing council meetings by the ECB where the policy rate is subject to change (as it is on every second governing council meeting). The securities in the two baskets we study are all bonds of various kinds. As bond return volatility is closely linked to changes in interest rates, the uncertainty before a governing council meeting, in which they decide on a change in the interest rate, is higher than on the day itself, when the decision is announced. Thus, we predict that the change in the collateral spread is negative, which is also what we find in the data.

These findings lend support to our theory and thus to the explanation for negative collateral spreads that emerge from it. Thus, in Section 1.5, we use our theory to provide a commentary on the development of the collateral spread in the euro area, as shown in Figure 1.1, over time.

The rest of the paper is organized as follows. In Section 1.2 we lay out the theoretical framework. Section 1.2 provides analysis of positive and negative collateral spreads and empirical predictions. The empirical tests are in Section 1.4. Section 1.6 concludes.

1.2 Theoretical framework

This section provides the theoretical framework that we will use to study variations in the collateral spread, the difference between unsecured and repo rates. We are especially interested in understanding under what conditions negative collateral spreads can arise and what are the other empirical implications of a model that is capable of yielding this. Important features in our setup include liquidity constrained players and collateral “pricing errors” (as discussed in the Introduction and further described below). To provide context for the model, we start by reviewing a generic repo.

1.2.1 Generic repurchase agreement

A generic repurchase agreement between two counterparties, a cash taker (borrower) and a cash provider (lender), has five main ingredients; the underlying collateral (e.g. a security), the price of the underlying collateral, the haircut that is applied to this price, the repo rate, and the maturity (tenor) of the repo agreement. For example, if the price (for the purpose of a repo) of the collateral is P, the haircut is h, and the repo rate is r, then the cash taker delivers the underlying collateral to the cash provider and receives cash of $P(1-h)$. At maturity, the cash taker buys back the underlying collateral at a

Table 1: *Basic cash flows in a repo/reverse repo**

	Date 0	Date 1 (maturity)
Repo (cash taker)	$1-h$	$-(1-h)(1+r)$
Reverse (cash provider)	$-(1-h)$	$(1-h)(1+r)$

* The price, P, of the collateral is normalized to 1 and the probability of default is assumed to be 0.

price equal to P plus the accumulated interest at the repo rate. The cash taker is said to be doing a repo while the cash provider is said to be doing a reverse repo.

In addition, the cash provider typically obtains the use of the collateral until maturity.[8] If we ignore this feature as well as the possibility of default, the cash flows arising from a repo that starts at date 0 and runs until date 1 are described in Table 1. These flows make the repo look like a simple (collateralized) loan of $1-h$ at the repo rate, r. However, this ignores that the cash provider has use of the collateral until maturity. In our model, this feature will play an important role.

1.2.2 Further structure and assumptions

We consider a setup where one agent, that we think of as a bank and refer to as "the short", is short one unit of liquidity. The shortage may arise from a need to fulfill reserve requirements, satisfy regulatory liquidity constraints, buy securities, or fulfill some obligation. The need to obtain the liquidity is modelled as a hard constraint. The short is assumed to be endowed with one unit of a security that can be used as collateral in a repo. She can obtain liquidity by selling the security in the cash market, doing a repo, or borrowing in the unsecured market. In the case the short does a repo, we refer to her as the cash taker, in line with standard terminology. Her potential counterparty is referred to as the cash provider.

We think of the cash provider as an intermediary between the short and banks with excess liquidity, alternatively as an arbitrageur in the market for liquidity. As a normalization, the cash provider is assumed to have no cash on hand at the start of date 0. Both the short and the cash provider are constrained in the unsecured market so that the total unsecured sum they can raise is less than the unit the short needs. This means that it is not feasible for the cash provider to finance a reverse repo that will provide the short with the liquidity she needs in the unsecured market. A fraction of the collateral held by the short will have to be sold in the cash market, either by the short herself or, in the

[8]For some CCP repos the cash provider may face constraints with respect to how to use the collateral. For example, in Eurex' GC Pooling contracts, the collateral can only be reused within Eurex' system or in repos with the Eurosystem. However, Eurex also provides settlement for other repo contracts where the collateral can taken outside Eurex' system (e.g. its Euro Repo baskets).

case she engages in a repo, by the cash provider. Constraints in the unsecured market are necessary to generate nonzero collateral spreads. This assumption will also lead to a link between the unsecured rate, the repo rate, and the cash market rate of return of the underlying collateral. We refer to a repo rate as an equilibrium repo rate if the short and the cash provider are willing to undertake a repo at that rate.

Assumption 1. *The maximum combined amount the short and the potential cash provider can obtain in the unsecured market is strictly less than one (i.e., the quantity of liquidity the short needs).*

The assumption of constraints in the unsecured market is consistent with anecdotal evidence that banks face interbank credit limits. It is also consistent with the findings of Bindseil, Nyborg, and Strebulaev (2009) that the interbank market is not perfectly allocationally efficient, even during times of normalcy. The unsecured rate is denoted by u and is assumed to be the same for the short and the potential cash provider.

To put further structure on the analysis, we make several additional assumptions as listed below.

Assumption 2. *There is no default risk.*

This is assumed in part because we wish to keep the theoretical analysis as simple as possible. It is also difficult to see how default, or credit, risk can lead to negative collateral spreads. The assumption of no default risk means that the theoretical analysis in this paper should perhaps best be viewed as representing one of overnight transactions, where default risk is arguably minimal.

Assumption 3. *Haircuts are exogenous to the repo itself. That is, the haircut, $h \in [0, 1)$, is not subject to negotiation between the counterparties.*

This reflects the factual situation in many repo agreements that haircuts are set in advance and often by a third party. For example, in the case of Eurex' repo contracts, a list of haircuts for each day is made available (weekly) on the Eurex website and (daily) in their system, Xemac. This is not updated during the day, except in special circumstances. As also noted by Mancini, Ranaldo, and Wrampelmeyer (2016) and Nyborg (2017b), haircuts in Eurex' GC Pooling contracts (that we use in our empirical analysis) are based on those set by the ECB for Eurosystem repos. These are updated only every three to four years (Nyborg, 2017b).[9] For US triparty repo agreements, Krishnamurthy, Nagel, and Orlov (2014) have observed that haircuts are not managed actively either and, according to Copeland, Martin, and Walker (2010), " ...haircuts are not negotiated at the trade

[9]Nyborg (2017b) also documents that Eurex deviates from the ECB haircuts in about 10% of cases.

level but are instead written into the appendix of the tri-party repo custodial agreement between the cash investor, the collateral provider, and the clearing bank. While it is possible to change the appendix containing the haircuts, the change may not apply until the next day. Such changes are only made occasionally."[10] In Europe, Clearstream and Euroclear, two triparty repo agents, ask banks to set their own haircuts according to certain security criteria (e.g. type of security, maturity, rating etc.) before they start trading repo in their systems. This list of haircuts can be amended and banks can apply additional margins in individual contracts. However, haircuts are not normally updated on a daily basis. Thus, we study repo rates and collateral spreads as a function of haircuts.

Assumption 4. *The date 0 price, for the purpose of the repo, of the underlying security (collateral) is normalized to 1. The actual (security) cash market price that a seller could obtain is* $1 - \varepsilon_0$*, where* $\varepsilon_0 \in [0, 1)$ *is a constant. At date 1, the cash market price of the underlying security is* $1 + \tilde{x} - \varepsilon_1$*, where* $\tilde{x}$ *is a random variable.*[11]

The parameter ε_t is the collateral pricing error arising from a lack of perfect liquidity or, at date 0, because the price used in the repo is based on a model. Even if a market price were used in a repo agreement, in practice, it is not clear that if additional securities were sold into the market, that the cash taker could actually achieve that price. The less liquid the underlying security is, the larger would the price discrepancy be expected to be. Because the ε's reflect illiquidity, we think of $\varepsilon_t \geq 0$. For simplicity, we assume that settlement in the cash market is immediate.[12]

Let $1 + \bar{x}$ denote the expected date 1 price of the underlying collateral in a perfectly liquid market without pricing errors. Since the date 0 price is normalized to 1, $\bar{x}$ is the expected rate of return in these perfect conditions. In contrast, the actual expected rate of return to an agent that buys in the cash market at date 0 and sells at date 1 is

$$\bar{y} = \frac{1 + \bar{x} - \varepsilon_1}{1 - \varepsilon_0} - 1 = \frac{\bar{x} - (\varepsilon_1 - \varepsilon_0)}{1 - \varepsilon_0}. \tag{1.1}$$

Similarly, we define the random variable

$$\tilde{y} \equiv \frac{\tilde{x} - (\varepsilon_1 - \varepsilon_0)}{1 - \varepsilon_0}. \tag{1.2}$$

[10]It is possible that haircuts in the bilateral repo market may be updated more frequently than for other repos, see e.g., (Gorton and Metrick, 2011).

[11] We also think of ε_1 being a constant so that we have an additive pricing error specification. However, the formulation also allows for a multiplicative pricing error. For a multiplicative specification, simply set $\varepsilon_1 = \varepsilon_1^*(1 + \tilde{x})$, where ε_1^* is a constant. At date 0, the price is normalized to 1 so that the pricing error specification in Assumption 4 can be viewed equally as additive or multiplicative.

[12]If settlement is instead the next day, for example, we could think of the repo studied here as a tomorrow/next transaction.

This represents the (security) cash market rate of return.

The short's objective is to raise one unit of liquidity at date 0 in the way that yields the maximum date 1 utility. The cash provider in a repo seeks to provide $1-h$ units of liquidity while also maximizing date 1 utility.

Assumption 5. *The short and the potential cash provider have CARA utility with risk aversion parameter ρ, and $\tilde{x}$ is normally distributed with mean $\bar{x}$ and variance σ_x^2.*

The cash market rate of return, $\tilde{y}$, is, therefore, also normally distributed with mean $\bar{y}$ and variance $\sigma_y^2 = \sigma_x^2/(1-\varepsilon_0)^2$. As shown by Grossman (1976), Assumption 5 leads to mean-variance preferences. For the analysis in the next section, it is useful to make some observations regarding the certainty equivalents of the returns obtained from various positions or trades of the security held by the short.

Position certainty equivalents

Using Grossman's (1976) arguments, we can establish that the certainty equivalent of receiving $\omega\tilde{x}$, $\omega \in [0,1]$, is $\omega\bar{x} - \frac{\rho}{2}\sigma_x^2\omega^2$, while the certainty equivalent of an outflow of $\omega\tilde{x}$ is [13]

$$\hat{x}(\omega) \equiv \bar{x}\omega + \frac{\rho}{2}\sigma_x^2\omega^2. \tag{1.3}$$

That is to say, an agent who has to pay $\omega\tilde{x}$ would be indifferent between paying this random sum or the fixed sum $\hat{x}(\omega)$. In general, given Assumption 5, the certainty equivalent of an outflow of $\omega\tilde{x} + a$, where a is a constant, is $\hat{x}(\omega) + a$.

Cash market certainty equivalents

The alternative to raising one unit of liquidity by doing a repo and borrowing h in the unsecured market is to sell ω units of the security in the cash market, borrow $1-\omega(1-\varepsilon_0)$ in the unsecured market, and then buying back ω units of the security at date 1. An agent that follows this strategy, has a net *outflow* of $\omega\left[\tilde{x} - (\varepsilon_1 - \varepsilon_0)\right]$ from the two cash market trades. The certainty equivalent of this is $\hat{x}(\omega) - \omega(\varepsilon_1 - \varepsilon_0)$. In other words, *per unit of cash raised at date 0*, the certainty equivalent of the net cash *outflow* from selling fraction

[13]Let $\tilde{z} = \omega\tilde{x}$. Thus, $\tilde{z}$ is normally distributed with mean $\bar{z} = \omega\bar{x}$ and variance $\sigma_z^2 = \omega^2\sigma_z^2$. The expected utility of receiving $\omega\tilde{x}$ is given by,

$$E[U(\omega\tilde{x})] = E[U(\tilde{z})] = \frac{-1}{\sqrt{2\pi}\sigma_z}\int_{-\infty}^{\infty} \exp\left(-\rho z\right)\exp\left(\frac{-(z-\bar{z})^2}{2\sigma_z^2}\right)dz = -\exp\left(-\rho(\bar{z} - \frac{\rho}{2}\sigma_z^2)\right),$$

where $E[\cdot]$ is the expectation operator, $U(\cdot)$ denotes the negative exponential (CARA) utility function, i.e. $U(z) = -\exp(-\rho z)$, and $\exp(z) \equiv e^z$. Thus the certainty equivalent of receiving $\omega\tilde{x}$ is $\omega\bar{x} - \frac{\rho}{2}\omega^2\sigma_x^2$. Similarly, $E[U(-\omega\tilde{x})] = -\exp\left(-\rho(\omega\bar{x} + \frac{\rho}{2}\omega^2\sigma_x^2)\right)$, implying that the certainty equivalent of an outflow of $\omega\tilde{x}$ is $\hat{x}(\omega)$ as defined in (1.3).

ω of the security at date 0 and buying this back at date 1 is[14]

$$\hat{y}(\omega) \equiv \frac{\hat{x}(\omega) - \omega(\varepsilon_1 - \varepsilon_0)}{\omega(1-\varepsilon_0)} = \frac{\bar{x} - (\varepsilon_1 - \varepsilon_0)}{1-\varepsilon_0} + \frac{\rho}{2}\frac{\omega\sigma_x^2}{1-\varepsilon_0} = \bar{y} + \frac{\rho}{2}\omega\sigma_y^2(1-\varepsilon_0). \qquad (1.4)$$

We refer to $\hat{y}(\omega)$ as the "adjusted rate of return," or "cost," from selling the fraction ω of the security at date 0 and buying it back at date 1. This terminology reflects that $\hat{y}(\omega)$ is adjusted relative to the fundamental expected rate of return of the security, $\tilde{x}$. As seen, $\hat{y}(\omega)$, is increasing in the fraction traded, ω. The additional adjustments are, in part, due to risk aversion and volatility and, in part, to illiquidity. In particular, the cash market adjusted rate of return from selling ω shares at date 0 and buying this back at date 1 is also increasing in risk aversion (ρ), volatility (σ_x^2), and illiquidity (ε_0). As seen in (1.4), $\hat{y}(\omega)$ is also increasing in $\bar{x}$.

1.3 Analysis

In our model, constraints in the unsecured market mean that at least a fraction of the security held by the short will have to be sold in the cash market. This may be done by the short herself or, in the case that she raises liquidity through a repo, by the cash provider in that repo. Recall that the cash provider is also constrained in the unsecured market and does not have excess liquidity. Thus, the cash provider needs to finance the reverse position by selling securities at date 0. In particular, we study unhedged reverse repos where the cash provider needs to sell at least a fraction of the underlying repoed collateral to finance his position. The existence of constraints in the unsecured market for both players and the need to trade in the cash market creates a link between the repo rate, the unsecured rate, and the collateral's cash market adjusted rate of return.

Before proceeding, we need to make Assumption 1 more precise. In particular, denote the maximum quantity the cash provider can obtain from the unsecured market by $\kappa \in [|h-\varepsilon_0|, 1)$. This ensures that the cash provider is able to finance a reverse repo. Denote the maximum quantity that the short can borrow by η . By Assumption 1, $\eta < 1-\kappa$. We assume $\eta \geq \max\{h, \varepsilon_0\}$ so that it is feasible for the short to raise the unit of liquidity she needs through either doing repo or trading in the cash market.

Given her constraints and her need to obtain one unit of liquidity, the short has two alternative sets of trades. She can either combine unsecured borrowing with a repo (Alternative 1) or with direct cash market trades (Alternative 2).[15] In Alternative 1,

[14]The second step in (1.4) uses (1.3) and the final step uses (1.1) and the expression for σ_y^2 above.

[15]We do not consider mixtures of repo and cash market sales by the short. Our focus is on these two as alternative approaches to raising liquidity, or, put differently, on the implications of viewing the cash market as a venue for creating a "home-made" repo where the "interest rate" is uncertain.

Table 2: *Cash flows from alternatives for raising one unit of liquidity*

	Date 0	Date 1
Alternative 1 (when $r \leq u$)		
Repo	$1-h$	$-(1-h)(1+r)$
Borrow unsecured	h	$-h(1+u)$
Sum	1	$-[1+(1-h)r+hu]$
Alternative 2		
Sell	$\omega(1-\varepsilon_0)$	–
Buy	–	$-\omega(1+\tilde{x}-\varepsilon_1)$
Borrow unsecured	$1-\omega(1-\varepsilon_0)$	$-(1-\omega(1-\varepsilon_0))(1+u)$
Sum	1	$-\omega(1+\tilde{x}-\varepsilon_1)-(1-\omega(1-\varepsilon_0))(1+u)$

the short prefers minimizing her unsecured borrowings if $r \leq u$ and maximizing them if $r > u$.[16] In Alternative 2, the optimal cash market trade and unsecured borrowings will have to be determined.

By way of illustration, the cash flows from the short's two alternatives are laid out in Table 2. For now, we assume that $r \leq u$. Thus, in the repo alternative, the short borrows the minimum amount, h, in the unsecured market and raises $1-h$ by repoing her security. In Alternative 2, the short sells ω units in the cash market, yielding a cash inflow of $\omega(1-\varepsilon_0)$, and borrows $1-\omega(1-\varepsilon_0)$ at the unsecured rate. At date 1, she buys back ω shares of the security and repays her loan, to yield the cash flows shown. In order to compare the two alternatives, it is necessary to first derive the optimal ω, subject to constraints, which we turn to next.

1.3.1 Alternative 2: Raising liquidity in the cash market

As seen in Table 2, the outflow at date 1 from the short's Alternative 2 is

$$\omega(1+\tilde{x}-\varepsilon_1)+(1-\omega(1-\varepsilon_0))(1+u).$$

Using (1.3), the certainty equivalent of this is

$$1+\hat{x}(\omega)-\omega(\varepsilon_1-\varepsilon_0)+(1-\omega(1-\varepsilon_0))u. \tag{1.5}$$

Using (1.4), this can be written as $1+c(\omega)$, where

$$c(\omega) \equiv \omega(1-\varepsilon_0)\hat{y}(\omega)+(1-\omega(1-\varepsilon_0))u. \tag{1.6}$$

[16]If $r = u$, the short is indifferent between raising liquidity through a repo or unsecured borrowing. In the anlaysis, we assume that the short borrows as little as possible in the unsecured market if $r = u$. Thus, we have two scenarios: $r \leq u$ and $r > u$.

$c(\omega)$ has the intuitive interpretation as the (adjusted) weighted average cost of liquidity under Alternative 2 when ω shares are sold in the cash market at date 0 and the remaining liquidity of $1-\omega(1-\varepsilon_0)$ is obtained in the unsecured market.

Thus, under Alternative 2, maximizing date 1 utility for the short is equivalent to choosing ω so as to minimize the weighted average cost of liquidity. In doing so, the short faces two constraints. First, it is not feasible for her to sell more of the security than the one unit she is endowed with. Second, since she cannot borrow more than η unsecured, she must sell at least $(1-\eta)/(1-\varepsilon_0)$ units. Hence, the short's problem is to solve the following constrained minimization problem:

$$\begin{array}{ll} \min_\omega c(\omega) \quad \text{subject to} & \\ \text{Feasibility:} & \omega \leq 1 \\ \text{Unsecured borrowing:} & \omega \geq \frac{1-\eta}{1-\varepsilon_0}. \end{array} \tag{1.7}$$

The first-order condition of the *unconstrained* problem is[17]

$$\omega^* \hat{y}'(\omega^*) + \hat{y}(\omega^*) - u = 0. \tag{1.8}$$

Thus, using (1.4), the unconstrained optimal cash market trade is

$$\omega^* = \frac{u-\bar{y}}{\rho\sigma_y^2(1-\varepsilon_0)}. \tag{1.9}$$

Hence, with respect to feasibility, $\omega^* \leq 1$ if and only if

$$u-\bar{y} \leq \rho\sigma_y^2(1-\varepsilon_0). \tag{1.10}$$

With respect to the unsecured borrowing constraint, $\omega^* \geq (1-\eta)/(1-\varepsilon_0)$ if and only if

$$u-\bar{y} \geq \rho\sigma_y^2(1-\eta). \tag{1.11}$$

The "upper bound" on $u-\bar{y}$ (for an unconstrained solution) in (1.10) is larger than the "lower bound" in (1.11) since $\eta \geq \varepsilon_0$. Thus, the constrained optimal cash market trade is

$$\Omega = \begin{cases} 1 & \text{if } u-\bar{y} \geq \rho\sigma_y^2(1-\varepsilon_0) \\ \omega^* & \text{if } \rho\sigma_y^2(1-\eta) \leq u-\bar{y} < \rho\sigma_y^2(1-\varepsilon_0) \\ \frac{1-\eta}{1-\varepsilon_0} & \text{if } u-\bar{y} < \rho\sigma_y^2(1-\eta). \end{cases} \tag{1.12}$$

[17]From (1.4), it is straightforward that $c''(\omega^*) > 0$. So the second order condition for a minimum is satisfied.

This says that if the unsecured rate is "very large" relative to the cost of cash market trades, the short optimally trades her whole unit. On the other hand, if the unsecured rate is "very low," the short trades as little as possible, preferring instead to borrow as much as she can in the unsecured market. Between these extremes, the unconstrained optimum obtains. In the limiting case that $\rho = 0$, $\Omega = 1$ if and only if $\bar{y} \leq u$, which is intuitive.

1.3.2 Positive collateral spread

In this subsection, we consider the case of positive collateral spreads. Negative spreads are considered in the next subsection.

We start by assuming that $r \leq u$. Our first objective is to derive necessary conditions for this to hold. Sufficient conditions are considered subsequently (in Theorem 1). Given that $r \leq u$, the short's two alternative trades are as laid out in Table 2, with $\omega = \Omega$ as given by (1.12). Using the analysis in Subsection 1.3.1, it follows from Table 2 that for the short to engage in a repo, we must have,

$$(1-h)r + hu \leq \Omega(1-\varepsilon_0)\hat{y}(\Omega) + (1 - \Omega(1-\varepsilon_0))u. \tag{1.13}$$

This is intuitive. It says that the interest cost of doing a repo (in combination with unsecured borrowing) must be no larger than the cost of trading in the cash market (in combination with unsecured borrowing). In turn, this implies that we have an upper bound on the repo rate as follows:

$$r \leq \overline{r} = \frac{\Omega(1-\varepsilon_0)\hat{y}(\Omega) + (1-\Omega(1-\varepsilon_0))u - hu}{1-h}. \tag{1.14}$$

This expression is derived under the assumption that $r \leq u$. Thus, if the right hand side of (1.14) exceeds u, the actual upper bound is u itself. This situation would indicate that the short would be willing to pay a larger rate in a repo than the rate she actually pays. This can occur if the short is more constrained in the unsecured market than the cash provider (see Theorem 1 and its proof).

Turning now to the cash provider, recall that he needs to finance the reverse repo by selling collateral at date 0. This may be combined with a loan in the unsecured market. In order to be able to deliver the collateral back to the short at date 1, the cash provider has to buy it back in the market at that time. At date 0, it is possible that the cash provider generates excess liquidity through the sale of the security in the cash market. If so, this is placed in the unsecured market at u. The cash provider, therefore, faces cash flows shown in Table 3, where α denotes the fraction of the underlying security he sells in the cash market to generate liquidity and finance the reverse repo.

Table 3: *Cash flows to the cash provider (when $r \leq u$)*

	Date 0	Date 1
Reverse	$-(1-h)$	$(1-h)(1+r)$
Sell security	$\alpha(1-\varepsilon_0)$	–
Unsecured loan	$1-h-\alpha(1-\varepsilon_0)$	$-(1-h-\alpha(1-\varepsilon_0))(1+u)$
Buy back security	–	$-\alpha(1+\tilde{x}-\varepsilon_1)$
Sum	0	$(1-h)(1+r)-(1-h-\alpha(1-\varepsilon_0))(1+u)$ $-\alpha(1+\tilde{x}-\varepsilon_1)$

The cash flows in Table 3 imply that for the (potential) cash provider to be willing to enter into the reverse repo, we must have (using (1.3) and (1.4)),

$$(1-h)r + hu \geq \alpha(1-\varepsilon_0)\hat{y}(\alpha) + (1-\alpha(1-\varepsilon_0))u. \tag{1.15}$$

This is the reverse of the condition for which the short is willing to enter a repurchase agreement, but with α substituting for Ω. To derive the optimal fraction to sell in the cash market for the cash provider, note that the problem he faces is identical to the problem faced by the cash taker under her Alternative 2, except that the cash provider's unsecured borrowing cap is κ rather than η. Thus, using the same argument as in Subsection 1.3.1, the cash provider's constrained optimal cash market trade is

$$A = \begin{cases} 1 & \text{if } u-\bar{y} \geq \rho\sigma_y^2(1-\varepsilon_0) \\ \omega^* & \text{if } \rho\sigma_y^2(1-\kappa) \leq u-\bar{y} < \rho\sigma_y^2(1-\varepsilon_0) \\ \frac{1-\kappa}{1-\varepsilon_0} & \text{if } u-\bar{y} < \rho\sigma_y^2(1-\kappa). \end{cases} \tag{1.16}$$

Equation (1.15) now implies that there is a lower bound on the repo rate which is given by

$$r \geq \underline{r} = \frac{A(1-\varepsilon_0)\hat{y}(A) + (1-A(1-\varepsilon_0))u - hu}{1-h}. \tag{1.17}$$

The expressions for the upper and lower bounds of r show that, in equilibrium, there is a constrained arbitrage relation between the repo rate, r, the unsecured rate, u, and the cash market rate of return of the underlying security. If $u-\bar{y}$ is larger than the maximum of $\rho\sigma_y^2(1-\kappa)$ and $\rho\sigma_y^2(1-\eta)$ then the upper and lower bounds coincide. These are given by the right hand side of (1.14). In other words, there is a unique equilibrium repo rate when the unsecured rate is so high that neither player's unsecured borrowing constraint is binding. When the constraint is binding for either player, the repo rate is indeterminate within the upper and lower bounds, or there is no equilibrium repo rate. In general, a positive collateral spread places an upper bound on the cash market rate, $\hat{y}(\cdot)$. These implications are stated more precisely in the theorem below.

Theorem 1. *If $\eta \leq \kappa$ (the short is more constrained in the unsecured market than the cash provider) then a necessary condition for $r \leq u$ is*

$$\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) = \bar{y} + \frac{\rho}{2}\sigma_y^2(1-\kappa) \leq u, \tag{1.18}$$

and a sufficient condition is

$$\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) = \bar{y} + \frac{\rho}{2}\sigma_y^2(1-\eta) \leq u. \tag{1.19}$$

If $\eta > \kappa$ (the short is less constrained in the unsecured market than the cash provider), $r \leq u$ if and only if

$$\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) + \frac{\rho}{2}\sigma_y^2(1-\kappa) = \bar{y} + \rho\sigma_y^2(1-\kappa) \leq u. \tag{1.20}$$

Furthermore, if $r \leq u$, we have

1. *If $u - \bar{y} \geq \rho\sigma_y^2(1-\varepsilon_0)$ then there is a unique equilibrium repo rate given by*

$$r = \frac{(1-\varepsilon_0)\hat{y}(1) + \varepsilon_0 u - hu}{1-h}. \tag{1.21}$$

2. *If $\rho\sigma_y^2 \max\{1-\eta, 1-\kappa\} \leq u - \bar{y} < \rho\sigma_y^2(1-\varepsilon_0)$ then there is a unique equilibrium repo rate given by*

$$r = \frac{\omega^*(1-\varepsilon_0)\hat{y}(\omega^*) + (1-\omega^*(1-\varepsilon_0))u - hu}{1-h} = u - \frac{1}{2}\frac{(u-\bar{y})^2}{\rho\sigma_y^2(1-h)}. \tag{1.22}$$

3. *If $\eta \leq \kappa$ and $u - \bar{y} < \rho\sigma_y^2(1-\eta)$ then r may take on any value in the interval $[\underline{r}, \min\{u, \overline{r}\}]$, where*

$$\overline{r} = \frac{(1-\eta)\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) + (\eta-h)u}{1-h} = \frac{(1-\eta)\left(\bar{y} + \frac{1}{2}\rho\sigma_y^2(1-\eta)\right) + (\eta-h)u}{1-h}, \tag{1.23}$$

and

$$\underline{r} = \begin{cases} u - \frac{1}{2}\frac{(u-\bar{y})^2}{\rho\sigma_y^2(1-h)} & \text{if } u - \bar{y} \geq \rho\sigma_y^2(1-\kappa) \\ \frac{(1-\kappa)\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) + (\kappa-h)u}{1-h} = \frac{(1-\kappa)\left(\bar{y} + \frac{1}{2}\rho\sigma_y^2(1-\kappa)\right) + (\kappa-h)u}{1-h} & \text{if } u - \bar{y} < \rho\sigma_y^2(1-\kappa). \end{cases} \tag{1.24}$$

Proof: See the appendix.

The theorem establishes that for the repo rate to be less than the unsecured rate, the cash market adjusted rate of return cannot be "too high." The exact bound depends on which player is more constrained in the unsecured market. However, in either case, it is always true that a repo rate below the unsecured rate involves the cash market expected rate of return of the underlying security also being less than the unsecured rate, that is, $\bar{y} \leq u$. Without risk aversion, the conditions in the theorem collapse to $r \leq u$ if and only if $\bar{y} \leq u$. With risk aversion, the unsecured rate must carry a premium over $\bar{y}$, with the lower bound of the premium depending the players' unsecured borrowing caps.

The link between the repo rate, the unsecured rate, and the cash market rate of return arises because, for the short, the alternative to a repo is a "home-made" repo through transacting in the cash market. Furthermore, for the cash provider, unsecured borrowing constraints imply that it is necessary to transact in the cash market of the underlying security in order to finance the reverse position. If neither players' unsecured borrowing constraint is binding in their respective cash market problems, the theorem establishes that there is a unique equilibrium repo rate which is, as is intuitive in this case, independent of the unsecured borrowing constraints.

However, if either of the borrowing constraints bind, the maximum repo rate the short is willing to pay, $\overline{r}$, and the minimum rate the cash provider requires, $\underline{r}$ diverge. When the short is more constrained, that is, $\eta \leq \kappa$, the short's constraint binds first and, in this case, we have $\overline{r} > \underline{r}$. The short is essentially willing to pay a premium over what the cash provider requires because his borrowing demand is unsatisfied (the constraint is binding) in the cash market alternative and the cash provider can funnel additional unsecured borrowings to the short through the device of the repo. In other words, the "home-made" repo is inferior to the market solution of an actual repo.

Raising liquidity by transacting in the cash market leads to more volatile realized financing costs than borrowing unsecured at a fixed rate. Thus, borrowing constraints can bind even though $\bar{y} < u$ because of risk aversion. This also explains the attraction of an actual repo as compared with the home-made version. When the cash provider is less constrained than the short, the repo alternative allows liquidity to be raised at a less volatile rate, thus lowering the risk-adjusted cost.

This helps explain why the sufficient and necessary bounds on $\hat{y}(\cdot)$ for $r \leq u$ diverge when the cash provider is less constrained. In this case, the sufficient condition is determined by the short's constraint, while the necessary condition is determined by the cash provider's more generous constraint. The short's constraint sets $\overline{r}$ which in this case exceeds $\underline{r}$. In turn, this makes the sufficient condition stronger than the necessary condition.

When the short is less constrained than the cash provider, an actual, market-based repo does not offer any advantage over the home-made alternative. As a result, there is always a unique repo rate and the necessary and sufficient conditions for $r \leq u$ coincide.

Our analysis provides constrained arbitrage relations between unsecured, cash market, and repo rates. It is predicated on the idea that two of these rates may diverge, for reasons outside of the model. As they diverge, this then has implications for the third rate. We think of the unsecured market and the cash market as the fundamental markets, with the repo market being derived from those. Our analysis reflects that the two fundamental markets have different participants and are subject to different shocks. The participants in the unsecured markets are banks trading reserves (central bank money). The participants in the security cash market is much broader. As is well known, the unsecured market is subject to up and down spikes that relate to the shift from an outgoing to a new reserve maintenance period (see, e.g., Hamilton (1996), for the US, or Nautz and Offermanns (2008), for the euro area) or particular calendar dates, e.g., (Fecht, Nyborg, and Rocholl, 2008; Perez-Quiros and Mendizabal, 2006). Securities markets do not experience the same extreme movements around the same dates and are subject to a different set of issues such as investors' rebalancing portfolios, information flows, market uncertainty, etc. Given that the unsecured rate does not move in lock-step with the cash market, the expressions for the repo rate in Theorem 1 will give rise to testable empirical predictions. However, we first need to study the case of negative collateral spreads.

1.3.3 Negative collateral spread

In this subsection, we derive necessary and sufficient conditions under which the collateral spread is negative. We assume $r > u$ and ask whether this is consistent with equilibrium (willingness to trade by both sides at that rate).

When $r > u$, the short optimally borrows her maximum of η in the unsecured market under Alternative 1 (repo) and repos the fraction

$$\phi = \frac{1-\eta}{1-h} \tag{1.25}$$

of her security.

Since the short faces the same situation in the cash market as before, her optimal transaction under Alternative 2 is still Ω as given in (1.12). By the conditions for $r \leq u$ in Theorem 1, we can restrict the values of $u - \bar{y}$ we need to consider when studying $r > u$. The theorem implies that $r > u$ is only possible if $u - \bar{y}$ is "small," where what this means exactly depends on whether the short is less or more constrained in the unsecured market than the cash provider.

In the discussion that follows, we assume that the short is more constrained than the cash provider, that is, $\eta \leq \kappa$. However, the case that $\eta > \kappa$ is also covered in the theorem below. Given $\eta \leq \kappa$, if $r > u$ is equilibrium, (1.19) in Theorem 1 implies

$$\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) = \bar{y} + \frac{\rho}{2}\sigma_y^2(1-\eta) > u. \tag{1.26}$$

Likewise, by (1.18) in Theorem 1, if

$$\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) = \bar{y} + \frac{\rho}{2}\sigma_y^2(1-\kappa) > u \tag{1.27}$$

then either $r > u$ or an equilibrium repo rate does not exist. To establish these as necessary and sufficient conditions, respectively, for $r > u$ when $\eta \leq \kappa$, we need to check whether the highest rate at which the cash taker is willing to do a reverse repo is larger than or equal to the lowest rate at which the cash provider is willing to take up the reverse position, given that parameter values obey (1.26) or (1.27).

Given $\eta \leq \kappa$, both (1.26) and (1.27) imply that a negative collateral spread is associated with the short's unsecured borrowing constraint being binding under Alternative 2. Thus, under this alternative, the short transacts $\Omega = (1-\eta)/(1-\varepsilon_0)$ and borrows η at the unsecured rate. Therefore, along the same lines as in the derivation of (1.13), for the short to be willing to do a repo, we must have

$$(1-\eta)r + \eta u \leq (1-\eta)\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) + \eta u \tag{1.28}$$

which reduces to

$$r \leq \overline{r}_{neg} = \hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) = \bar{y} + \frac{\rho}{2}\sigma_y^2(1-\eta). \tag{1.29}$$

More generally, this is the maximum the short is willing to pay whenever $u - \bar{y} \leq \rho\sigma_y^2(1-\eta)$.

The cash provider's problem is essentially the same as when $r \leq u$, except that he now needs to finance $\phi < 1$ units. This changes the feasibility constraint in his optimization problem, but the unconstrained problem and the borrowing constraint remain the same. Thus, the cash provider's optimal trade is now

$$A = \begin{cases} \phi & \text{if } u - \bar{y} \geq \rho\sigma_y^2(1-\varepsilon_0)\phi \\ \omega^* & \text{if } \rho\sigma_y^2(1-\kappa) \leq u - \bar{y} \leq \rho\sigma_y^2(1-\varepsilon_0)\phi \\ \frac{1-\kappa}{1-\varepsilon_0} & \text{if } u - \bar{y} \leq \rho\sigma_y^2(1-\kappa). \end{cases} \tag{1.30}$$

If $(1-\varepsilon_0)\phi \leq 1-\kappa$, the feasibility constraint will always bind so that, trivially, $A = \phi$. However, a binding feasibility constraint is not necessarily consistent with a negative collateral spread. For example, if $h \geq \varepsilon_0$ then $A = \phi$ is incompatible with $r > u$ because the necessary condition (1.26) would be violated.[18] We will come back to the feasibility of $A = \phi$ below.

Since the cash provider extends η in liquidity to the short in the repo (rather than h as when $r \leq u$), the condition for him to be willing to do a repo becomes

$$(1-\eta)r + \eta u \geq A(1-\varepsilon_0)\hat{y}(A) + (1 - A(1-\varepsilon_0))u. \tag{1.31}$$

Thus, the lowest acceptable repo rate to the cash provider is

$$r \geq \underline{r}_{neg} = \frac{A(1-\varepsilon_0)\hat{y}(A) + (1 - A(1-\varepsilon_0))u - \eta u}{1-\eta}. \tag{1.32}$$

Thus, to verify whether $r > u$ is possible, we need to compare this lower bound on r with the upper bound derived above. Similar considerations apply if $\kappa < \eta$.

Theorem 2. *If $\eta \leq \kappa$ (the short is more constrained in the unsecured market than the cash provider) then necessary and sufficient conditions for a negative collateral spread, $r > u$, are given by (1.26) and (1.27), respectively.*

Furthermore, if $\eta < \kappa$ and $r > u$ then r may take on any value in the interval $(\underline{r}_{\text{neg}}, \overline{r}_{\text{neg}}]$, where $\overline{r}_{\text{neg}}$ is given by (1.29) and

$$\underline{r}_{\text{neg}} = \begin{cases} \frac{\frac{1-\eta}{1-h}(1-\varepsilon_0)\hat{y}\left(\frac{1-\eta}{1-h}\right) + (1 - \frac{1-\eta}{1-h}(1-\varepsilon_0)u) - \eta u}{1-\eta} & \text{if } u - \bar{y} \geq \rho\sigma_y^2(1-\varepsilon_0)\phi \\ u - \frac{1}{2}\frac{(u-\bar{y})^2}{\rho\sigma_y^2(1-\eta)} & \text{if } \rho\sigma_y^2(1-\kappa) \leq u - \bar{y} \leq \rho\sigma_y^2(1-\varepsilon_0)\phi \\ \frac{(1-\kappa)\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) + (\kappa-\eta)u}{1-\eta} & \text{if } u - \bar{y} \leq \rho\sigma_y^2(1-\kappa). \end{cases} \tag{1.33}$$

If $\eta = \kappa$ and $r > u$ then there is a unique repo rate given by

$$r = \hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right). \tag{1.34}$$

If $\eta > \kappa$ (the short is less constrained in the unsecured market than the cash provider), a negative collateral spread is not possible unless the feasibility constraint trivially binds, that is, $(1-\varepsilon_0)\phi \leq 1-\kappa$. In this case, (1.26) is a necessary and sufficient condition for a negative collateral spread and the repo rate is given by the upper expression in (1.33).

Proof: See the appendix.

[18] To see this, if $A = \phi$, then $u - \bar{y} \geq \rho\sigma_y^2\frac{1-\varepsilon_0}{1-h}(1-\eta) \geq \rho\sigma_y^2(1-\eta)$ if $h \geq \varepsilon_0$. This is not compatible with (1.26), which states that $u - \bar{y} < \frac{\rho}{2}\sigma_y^2(1-\eta)$.

The theorem establishes that if the short is more constrained in the unsecured market than the cash provider, then the necessary and sufficient conditions for a negative collateral spread are just the reverse of the conditions for a positive collateral spread. However, if cash takers are less constrained than cash providers, a negative collateral spread is not consistent with equilibrium. One may therefore interpret the fact that negative collateral spreads are common as being consistent with the intuitive idea that cash providers are less constrained, or put differently, have "easier" access to liquidity, than cash takers.

The reason a negative collateral spread is not possible when $\eta > \kappa$ relates to the fact that a negative collateral spread implies that the potential cash provider's unsecured borrowing constraint is binding (by Theorem 1) – except when the feasibility constraint trivially binds. As discussed after that theorem, when the cash provider faces tighter borrowing constraints and these are binding, the short can do better through a home-made repo than going through the repo market. The maximum rate the short is willing to do a repo at falls below the minimum rate that is acceptable to the constrained cash provider.

We motivated our paper with reference to the puzzle of negative collateral spreads. Our theory says (roughly) that this may occur when the unsecured rate drops below the adjusted rate of return in the securities market. This may occur as a result of conditions in the unsecured market. It may also occur if securities prices drop so that their adjusted rate of return rise. Thus, negative collateral spreads may be a function of depressed securities prices.

1.3.4 Remark: Role of constraints

In our model, there are potentially two riskfree rates, the repo and the unsecured rates, since the setup excludes credit risk by Assumption 2. This does not give rise to arbitrage because of the assumption that both the short (cash taker) and the cash provider are constrained in the unsecured market. If we dropped Assumption 1 then an alternative to the short is to borrow the unit of liquidity she needs at a rate of u, implying that r cannot exceed u. From a cash provider's perspective, it is clear that r cannot be less than u. Thus, with no constraints in the unsecured market, we must have $r = u$. The fact that these rates are rarely equivalent in practice suggests that there are constraints in the unsecured market.[19] This makes sense since there is a limited quantity of reserves in the economy. The expressions for the repo rate in Theorems 1 and 2 also show that variations in these constraints can contribute to volatility in the collateral spread.

Our results bear some relation to those in Duffie (1996), although his focus is on special

[19] Repo and unsecured rates could also differ due to differential trading costs.

repo rates. In particular, he finds that the special repo rate $R \leq i$, the riskfree rate. His result is driven by trading asymmetries whereby one needs to hold the specific collateral in order to short it. In our model, it is also not possible to sell more than what is owned. However, in Duffie's model, unlike in ours, a player can always borrow at the riskfree rate. This makes the specific security more expensive relative to the bond, resulting in a special repo rate lower than the riskfree rate. Our result is analogous in that $r \leq u$ as long as the unsecured rate is above the cash market adjusted rate of return of the security, which one can think of as the underlying security being relatively "expensive." However, in our model, the reverse is also possible when the underlying security is relatively "cheap."

1.3.5 Empirical predictions

In this subsection, we develop several predictions resulting from the analysis of the collateral spread. The various scenarios we have considered above yield different expressions for the repo rate and, therefore, for the collateral spread. Here, we highlight three formulas for the collateral spread, if it is positive, and one, if it is negative.

If the complete security is sold, so that the feasibility constraint is hit, the collateral spread, using (1.21), is equal to

$$u - r = \frac{1-\varepsilon_0}{1-h}\left(u - \hat{y}\left(1\right)\right). \tag{1.35}$$

If the collateral spread is positive and the short and cash provider are unconstrained, the collateral spread using (1.22) is equal to

$$u - r = \frac{\omega^*(1-\varepsilon_0)(u-\hat{y}(\omega^*))}{1-h} = \frac{1}{2}\frac{(u-\bar{y})^2}{\rho\sigma_y^2(1-h)}. \tag{1.36}$$

In addition, if the repo rate is determined by (1.19), in which case the short is constrained, the collateral spread, using the upper bound $\overline{r}$, is equal to

$$u - \overline{r} = \frac{1-\eta}{1-h}\left(u - \hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right)\right). \tag{1.37}$$

There is one formula for the collateral spread if it is negative and both are constrained, using (1.27)

$$u - \underline{r} = \frac{1-\kappa}{1-\eta}\left(u - \hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right)\right). \tag{1.38}$$

From these formulas, we can derive a set of testable predictions.

Prediction 1. *We identify six predictions:*

1. *If there is an exogenous positive (negative) shock to u, the collateral spread rises (falls).*

2. *The collateral spread is increasing in haircuts (h), if $u > r$.*

3. *The collateral spread is decreasing in volatility (σ_y^2).*

4. *The collateral spread is decreasing in risk aversion (ρ).*

5. *The collateral spread is decreasing in the illiquidity of the underlying repoed security (ε_0).*

6. *Call $(u - \bar{y})/\rho\sigma_y^2$ the "unsecured rate premium." The more constrained the players are in the unsecured market, that is, the smaller are the borrowing caps, η and κ, the "more often" is the collateral spread negative (that is, the higher are the values of the unsecured rate premium associated with a negative collateral spread).*

It can be seen from the formulas of the collateral spread that a shock to u, but not to the risk-adjusted return $\hat{y}(\cdot)$, similarly affects the collateral spread. This is due to the relationship between the unsecured rate u, the risk-adjusted return $\hat{y}(\cdot)$ and the repo rate r, as given by equations (1.13) and (1.15) (in case of a negative collateral spread by (1.28) and (1.31)).

From the formulas of the collateral spread, it is obvious that the collateral spread depends positively on the haircut in absolute terms. A larger haircut forces the short and cash provider to seek more funding in the unsecured market in the repo alternative if $u > r$, decreasing the attractiveness of repo.

From (1.4) we know that $\hat{y}(\cdot)$ relates positively to volatility (σ_y^2). A larger $\hat{y}(\cdot)$ due to higher volatility makes the cash market alternative, the home-made repo transaction, less attractive for the short, thus she is willing to pay a higher repo rate. The same argument holds for risk aversion. Thus, the collateral spread is decreasing in both arguments.

Given (1.4), $\hat{y}(\cdot)$ is also decreasing in ε_0, the pricing error of the repo security. This implies, if its liquidity decreases, the collateral spread will increase. This also implies that baskets that contain less liquid securities should on average have a lower collateral spread. Bartolini, Hilton, Sundaresan, and Tonetti (2011) observe this empirical fact for the US data.

The smaller η and κ are, the larger are $\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right)$ and $\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right)$, the necessary and sufficient bounds for the negative collateral spread. If those bounds rise, there is a higher "chance" for the collateral spread to be negative, and should lead to more instances of a negative collateral spread.

1.4 Empirical analysis

In order to test predictions of our model of the collateral spread, we use data on unsecured and repo rates. As unsecured rate we take the Eonia, which is a volume-weighted average of overnight unsecured transactions by European reporting banks. Abbassi, Bräuning, Fecht, and Peydró (2014) provide evidence that trading in the unsecured market is still very active after the start of the financial crisis and the collapse of Lehman Brothers (September 15, 2008). On the repo rate, we have complete data for the period January 01, 2007 to June 30, 2015, which was obtained from Eurex Repo, who offers a trading platform for anonymous repo transactions. The data consists of transactions on a large number of repo contracts. Because our model focuses on the possibility of raising liquidity, we look at general collateral contracts (GC).[20] According to Duffie (1996), the GC market is the typical financing market, whereas the special repo market is driven by the demand for specific securities. Among GC contracts, we focus on two particular ones, namely GC Pooling ECB and GC Pooling ECB Extended baskets.[21] These two GC Pooling contracts are by far the most active baskets and they have the largest volume in overnight transactions, and thus can be easily matched to the Eonia. Other contracts have much smaller volume and are mainly traded tomorrow/next, which makes a clean matching to the Eonia difficult. The tests in this section are therefore based on these GC Pooling contracts. For these two contracts, we calculate the volume-weighted average repo rate per day, yielding a time series for each collateral spread. We will implement three tests on these collateral spreads, as outlined in the following sections.

1.4.1 Data on GC repo contracts

The transaction data consists of 261,663 GC transactions in the period January 01, 2007 to June 30, 2015. There are two GC markets operated by Eurex Repo: GC Pooling and Euro Repo. GC Pooling (GCP) includes the ECB and ECB Extended basket, as well as a basket containing equities. GCP ECB and ECB Extended baskets are subsets of the securities eligible at the Eurosystem (30,000-40,000 securities). GCP ECB basket contains about 7,000 securities, and GCP ECB Extended basket about 20,000. In Euro Repo, the counterpart to the GC Pooling market, baskets are constrained to one type of security, e.g. French covered bonds. The minimum rating allowed in Euro Repo and in GCP ECB basket is A-. The lowest rating in the GCP ECB Extended basket is BBB-. There are two important differences between GC Pooling and Euro Repo. The first main difference is that in GC Pooling transactions the cash taker pledges securities on

[20] For an analysis of special repo transactions based on the same data, please look in Chapter 2.

[21] Baskets are defined as a list of securities that can be used as collateral.

his collateral account, whereas in Euro Repo he transfers these securities physically to the counterparty's account. That is, re-use in Euro Repo has no limitations. Collateral obtained in a GC Pooling transaction can only be used for other GC Pooling transactions, or in the case of the ECB basket, as collateral at the CCP (e.g. futures contracts), and for obtaining liquidity from the Eurosystem. The second main difference is that securities haircuts in the GC Pooling basket are derived from haircuts in Eurosystem operations (Mancini, Ranaldo, and Wrampelmeyer, 2016).[22] Nyborg (2017b) provides evidence that they are identical in around 90% of cases. Eurex may increase haircuts for paper where it deems risk to be especially large. In contrast, Euro Repo haircuts are set by the Clearing Counterparty (CCP) Eurex Clearing without reference to Eurosystem haircuts. Trading in both GC Pooling and Euro Repo is open to credit institutions and investment firms. All trades are anonymous, cleared by the CCP Eurex Clearing, and settled by Clearstream. Participants can choose between different terms: overnight, tomorrow/next, spot/next, longer-term and variable terms.

[**insert Table 1.1 about here**]

Table 1.1 reports volume and rate statistics for GC baskets in both the GC Pooling and the Euro Repo markets. There are in total 28 baskets (GC Pooling and Euro Repo), which are ranked by transaction volume by trading day in the time period January 01, 2007 to June 30, 2015. The most transactions in the sample period take place in the GCP ECB and ECB Extended baskets (84% of all GC trades). For these two baskets, the majority of trades is overnight, whereas for Euro Repo baskets the most common term is tomorrow/next, with the percentage exceeding 50% for 13 baskets. The collateral spread is calculated as the difference between the Eonia and the volume-weighted average repo rate for the same contract period. The repo rate used for GC Pooling ECB and ECB Extended basket is overnight, and tomorrow/next for all other baskets. The largest collateral spread belongs to Germany 10 Year GC basket, which contains only sovereign bonds, with 15 basis points (bps), whereas the lowest bond collateral spread pertains to Euro Covered bonds with -6.14 bps. This indicates that the collateral spread, as we state in our theory, depends on the liquidity of securities in the basket.

The largest total volumes occur in the GCP ECB and ECB Extended basket, EUR 87 and 31 trillion, respectively. They also display the largest volume by trading day, EUR 40.3 billion and EUR 18.3 billion. So clearly, GCP ECB and ECB Extended baskets are the most actively traded baskets. Thus, in our tests below, we use the collateral spreads, Eonia – GCP ECB rate and Eonia – GCP ECB Ext. rate (The ECB basket exists for the

[22]The Eurosystem refers to the group of national central banks of the 19 Eurozone members led by the European Central Bank (ECB).

whole sample period, whereas the first trade in GC Pooling Extended basket can only be observed on November 24, 2008.).

[**insert Table 1.2 about here**]

A first impression of the time series of collateral spreads can be gained from Figure 1.1. Descriptive statistics are reported in Table 1.2. The collateral spreads are on average positive, the Eonia – GCP ECB rate has a mean of 3.77 bps, and the Eonia – GCP ECB Ext. rate has a mean of 1.36 bps, both significant at the 1% level. The median is also positive for both, 4.11 bps and 2.37 bps, respectively. The collateral spread of the ECB Extended basket is lower than the collateral spread of the ECB rate in 97.5% out of its 1,604 observations. The list of securities in the ECB Extended basket include a wider range of securities, in particular less liquid securities, increasing the average pricing error ε_0, which lowers the collateral spread according to our theory. This is also reflected in the percentage of negative days that we observe. The collateral spread Eonia – GCP ECB rate has 22.89% negative days, whereas the collateral spread of the ECB Extended basket has 28.74% negative days. This observation is coherent with our prediction above that a larger pricing error leads to a lower collateral spread. It is also in line with the results by Bartolini, Hilton, Sundaresan, and Tonetti (2011) who show that different types of securities differ in their collateral values, and those with the highest have the lowest repo rate.

1.4.2 Empirical test – Spikes

In this section we focus on spikes of the unsecured rate and the effect on the collateral spread, in order to test the relationship between the unsecured rate u, the risk-adjusted return $\hat{y}(\cdot)$, and the repo rate r. The repo rate is bound by u and $\hat{y}(\cdot)$, as determined by equations (1.13) and (1.15) (in case of a negative collateral spread by (1.28) and (1.31)). Roughly speaking, if the collateral spread is positive, r and $\hat{y}(\cdot)$ are smaller than u. If there is an exogenous shock to u, so that the risk-adjusted return $\hat{y}(\cdot)$ is unaffected, the repo rate moves into the same direction as the unsecured rate, but less due to its other link to $\hat{y}(\cdot)$. So if u jumps up, the collateral spread increases; if it jumps down, the collateral spread turns negative.

This is based on the unsecured rate and the risk-adjusted return being determined in two different markets: the unsecured rate in the interbank market, and the risk-adjusted return in the cash market. Both markets have different players. In the unsecured market one can only find banks, whereas the securities cash market is populated by all types of investors. Since banks depend on the liquidity supply by the Eurosystem, their liquidity demand is affected by the Eurosystem's institutional framework. This gives rise to calendar day effects in the unsecured rate, as documented by several papers, as for example Perez-Quiros and Mendizabal (2006) and Bindseil, Nyborg, and Strebulaev (2009).[23] In addition, there is an end-of-month effect due to balance sheet reporting and liquidity management (Bindseil, Weller, and Wuertz, 2003; Fecht, Nyborg, and Rocholl, 2008). We are not aware of calendar day effects in the securities cash market. So this is the ideal environment to test the relationship between the unsecured rate, the risk-adjusted return and the repo rate.

Originally, the Eurosystem follows a liquidity neutral policy before the collapse of Lehman Brothers on September 15, 2008 (Nyborg, Bindseil, and Strebulaev, 2002), in order to keep short-term interest rates close to its policy rate. A liquidity neutral policy means that the Eurosystem aims to inject only as much liquidity as needed into the financial market, so that banks are able to fulfill on average their reserve requirements over the maintenance period (between four and six weeks long). The Eurosystem conducts weekly auctions for liquidity with a term of one week, which banks access to satisfy their liquidity needs.[24] However, the Eurosystem cannot perfectly predict the amount needed, and even though short banks bid more aggressively for liquidity in the last auction of the maintenance period (Bindseil, Nyborg, and Strebulaev, 2009), liquidity will not be distributed optimally according to needs. So there will be banks that are long and other banks that are short in cash in the last week of the maintenance period, potentially even if total liquidity supply exceeds liquidity needs. This imperfect allocation of liquidity leads to jumps in the unsecured rate at the end of the maintenance period. Our theory predicts that the repo rate changes less than the unsecured rate, due to its arbitrage link to $\hat{y}(\cdot)$. Thus, the collateral spread moves into the same direction as the unsecured rate.

Before we turn to the reaction of the collateral spread, we demonstrate the existence of spikes in the unsecured rate based on the extant work cited above. We analyze the spikes of the unsecured rate in the last week of the maintenance period and on the last day of the month. Since we focus on the period, when the liquidity neutral policy by the Eurosystem is in place, our spikes tests focus on the period January 01, 2007 to August 30, 2008. In order to detect spikes, we calculate the mean and the standard deviation of the Eonia for each maintenance period excluding the last five days and the last trading day of the month. For those last five days of the maintenance period and the last day of

[23] Such calendar effects also exist in the Fed funds market in the US, see, e.g. Hamilton (1996).

[24] For a description of the standard Eurosystem monetary policy framework please refer to European Central Bank (2002).

the month we compute the standardized Eonia, which is defined as:

$$stand.\ Eonia_t = \frac{u_{t,m} - \overline{u_m}}{\sigma_m}, \tag{1.39}$$

where the subscript m denotes the maintenance period, and t refers to the day within the maintenance period. $\overline{u}_m$ (σ_m) is defined as the average (standard deviation) of the unsecured rate during the maintenance period, excluding the last five days of the maintenance period and the last day of the month. The last five days of the maintenance period are denoted *endmp* to $endmp - 4$, with *endmp* being the last day. *monthend* refers to the last day of the month. The standardized Eonia is thus calculated as the difference between the Eonia on the last day of the month, *endmp*, and the average, $\overline{u_m}$, divided by the standard deviation, σ_m. The same procedure is repeated for the other days of the last week of the maintenance period, $endmp - 1$ to $endmp - 4$, and the last day of the month, *monthend*.

We have two tables, which show the values of the standardized Eonia on the days we are interested in, to detect and measure the size of spikes. The first table (Table 1.3) ranks all values of the standardized Eonia within each maintenance period and displays the ranks for the last five days of each maintenance period, *endmp* to $endmp - 4$, and the end of the month, *monthend*.

The order of ranking in Table 1.3 is determined by the sign of the standardized Eonia on the last day of the maintenance period, *endmp*. If it is negative, all values in the maintenance period are ranked in ascending order, starting with the lowest negative value. If the sign of the standardized Eonia on the last day of the maintenance period is positive, the ranking is in descending order. The same ranking is done for the last day of the month, but uncoupled from the ranking for the last days of the maintenance period, e.g. in case it has the largest positive value, it obtains the first rank. That is, if e.g. the last day of the maintenance period has the lowest negative value, and the last day of the month the largest positive value, both days will get the first rank. In 15 out of 20 maintenance periods, the last five days of the maintenance period contain the first rank, i.e. the day with the largest standardized Eonia (either positive or negative). In two periods the standardized Eonia exceeds 100 in absolute value, i.e. the Eonia is 100 standard deviations away from the mean. In the other periods, its absolute value (first rank) is between 1.93 and 24.85. This illustrates end-of-maintenance period and end-of-month spikes in the unsecured rate, in line with the findings by the extant literature (Bindseil, Weller, and Wuertz, 2003; Fecht, Nyborg, and Rocholl, 2008; Nautz and Offermanns, 2008).

[insert Table 1.3 about here]

The second table (Table 1.4) aggregates this information and provides consolidated statistics of the standardized Eonia on the last five days of the maintenance period and the end of the month. It presents the average as well absolute values of the standardized Eonia for the last five days of the maintenance period and the last day of the month across the 20 maintenance periods, during which the ECB operates with liquidity neutral policy. The lowest average value of -7.68 (including up- and down spikes) occurs on the last day of the maintenance period, indicating that negative jumps are more sizeable. When splitting the average value into averages of positive and negative values, the negative values of the standardized Eonia are more than twice the value of the positive jumps in absolute terms. In absolute terms the standardized Eonia is 16.31 on that day, i.e. it is 16 standard deviations away from the mean. The absolute value is decreasing in the lags of the last day, the lowest value on $endmp - 4$ being 2.42. Still, the standardized Eonia is two standard deviations away from the mean on this day. At month-end, the standardized Eonia spikes upwards exceeding two standard deviations on 65% of those days. This further demonstrates that the Eonia rate jumps at the end of the maintenance period and the end of the month.

[**insert Table 1.4 about here**]

After analyzing the Eonia spikes we now turn to analyze their effects on the collateral spread. Thus, we conduct two time series regressions. In the first specification we calculate the 10% and 90% percentile of the unsecured rate, Eonia, in each maintenance period to identify its spikes. Then we regress the collateral spread, Eonia – GCP ECB rate, on two dummies capturing the 10th and 90th percentiles of the Eonia (*perc10*, *perc90*), a dummy for the last day of the month (*monthend*), and a dummy for the crisis period (*fincrisis*). The variables *perc10* and *perc90* represent the days with lowest and highest Eonia, respectively, within the maintenance period. In our second specification we condition those two percentile dummies on the last five days of the maintenance period and the other days. That is, we include two dummies for the 10th and 90th percentiles outside the last five days of the maintenance period ($perc10|nonendres$,$perc90|nonendres$), and two dummy variables for the 10th and 90th percentile within the last five days of the maintenance period ($perc10|endres$, $perc90|endres$). The last day of the month is not included when determining *perc10* and *perc90*. Standard errors are corrected by using Newey-West with five lags (Greene, 2008). The second specification, thus, looks as follows:

$$\begin{aligned} y_t =& \beta_0 + \beta_1 perc10|nonendres_t + \beta_2 perc90|nonendres_t \\ &+ \beta_3 perc10|endres_t + \beta_4 perc90|endres_t + \beta_5 fincrisis_t + \beta_6 monthend_t + \varepsilon_t. \end{aligned} \tag{1.40}$$

Table 1.5 displays the results. In the first column, *perc10* and *perc90* are not split into the end and the other days of the maintenance period. The coefficient of *perc10* is significant at the 5% level and the coefficient of *perc90* at the 10% level. If the Eonia is in the 10th percentile, so that *perc10* is equal to one, the collateral spread spikes down by 3.20 bps. It shoots up by 2.14 bps, when the Eonia is above the 90th percentile. This indicates that the jump in the unsecured rate is in general not matched by a similar jump in the repo rate. Downspikes in the unsecured rate thus tend to lead to negative collateral spreads.

[**insert Table 1.5 about here**]

The second column of Table 1.5 presents the results, when the observations of spikes are conditioned on the last five days of the maintenance period and the other days. This differentiation shows that the effect concentrates on the days within the last week of the maintenance period. The coefficients on $perc10|nonendres$ and $perc90|nonendres$ are insignificant. The coefficients on the percentiles conditioned on the last five days are significant at the 1% level and larger in absolute value than the coefficients without conditioning. If the Eonia is in the 10th (90th) percentile, the collateral spread decreases (increases) by 5.2 (6.16) bps. As the constant is close to zero (-3 bps in the financial crisis period), the collateral spread is positive if Eonia jumps upwards and negative, if it jumps downwards, confirming our prediction. This is especially strong evidence for our theory, because it is at the end of the maintenance period that the unsecured rate starts to "live its own life" as end-of-maintenance period considerations start to dominate.

The reaction of the collateral spread to Eonia spikes shows that the Eonia moves more than the repo rate, as we expected. The spikes at the end of the maintenance period occur due to factors outside the securities cash market, the operational framework by the Eurosystem. So the risk-adjusted return is not affected, and thus restrains the repo rate from jumping as much as the unsecured rate.

1.4.3 Empirical test – Change in haircuts

In this section we build a test around an exogenous change to haircuts. Our model predicts that the collateral spread is increasing in absolute terms in haircuts (Section 1.3.5). If the collateral spread is positive, $u - r$, a larger haircut implies that the short has to borrow more in the unsecured market, lowering her willingness to use repo instead of the cash market. Thus, the repo rate is lower, and the collateral spread is higher. The positive collateral spread is given by (1.35), (1.36), or (1.37), depending on the borrowing and feasibility constraints. Haircuts in GC Pooling follow those determined by the Eurosystem (Mancini, Ranaldo, and Wrampelmeyer, 2016), i.e. they are equal in about 90% (shown by Nyborg (2017b), Table 5.6). As Nyborg (2017b) emphasizes, the Eurosystem has adjusted its haircuts on average only every three to four years. Thus, GC

Pooling haircuts are truly exogenous.[25] Since haircuts, which serve as a risk management tool, are only updated infrequently, they are not set in response to developments in money markets. Thus, a change to haircuts provides a natural experiment for the effect on the collateral spread.

During our sample period the Eurosystem changes its haircuts four times. We use the third haircut adjustment in our test, which is announced on September 27, 2013 and implemented on October 01, 2013, as it occurs during a calm period and involves a wide-ranging adjustment of haircuts. For a large amount of securities, the ECB lowers haircuts. So haircuts in the GC Pooling baskets fall as well (Mancini, Ranaldo, and Wrampelmeyer, 2016; Nyborg, 2017b).

According to the ECB collateral framework, securities are given a haircut based on their type of security and time to maturity, as well as rating.[26] Securities are classified into five categories: I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities. The change in ECB haircuts is displayed in Table 1.6 (computed from Tables 5.3 and Tables 5.4 in Nyborg (2017b)). For the securities rated A- to AAA, the largest changes occur in Category III (apart from Category V, which is not eligible in Eurex Repo). Haircuts of securities rated A- to AAA decrease in Categories I to III. For securities rated BBB-to BBB+, haircuts increase in the first two categories and decrease for the last three categories. In general, less liquid and lower quality securities receive a lower haircut than before (except for Categories I and II, BBB+ to BBB-).

[insert Table 1.6 about here]

Tables 1.7 and 1.8 show the distribution of securities in GC Pooling baskets across categories on September 26, 2013. The GC Pooling baskets only contain securities from Category I to Category IV. The lowest rating in the ECB basket is A-, whereas the Extended basket also includes securities rated BBB- to BBB+. The largest category in the ECB basket is Category III (48% of no. securities). In the ECB Extended basket, Category IV with 58% is the largest. In addition, the majority of securities (94%) in the Extended ECB basket is rated with a minimum of A-. In general, banks will use securities in repo that are the cheapest to deliver. As we have data on GC Pooling haircuts from September 16 to October 15, 2013, we can calculate on each day the average haircut for each basket across securities. The average haircut for both baskets can be seen in

[25] GC Pooling haircuts are published daily in the Eurex Repo trading system.

[26] An exact description of this framework can be found in Nyborg's book *Collateral Frameworks - The Open Secret of Central Banks*, Tables 5.1 to 5.4.

Figure 1.4, in which the change in haircuts is evident. Average haircuts in the GCP ECB basket fall by 84 bps, whereas in GCP ECB Extended basket by 49 bps. The development of the GC Pooling rates can be seen in Figure 1.5 and the spreads in Figure 1.6. These figures suggest that repo rates and collateral spreads move as predicted following the change in haircuts.

[**insert Figure 1.4 and Tables 1.7, 1.8 about here**]

The effect of the change in haircuts on the collateral spread is now tested formally. We study periods of two weeks, three weeks and four weeks around the announcement day. These narrow time windows allow us a good identification of this effect. The following days are removed from the sample: the announcement day, September 27, 2013, was taken out. The last day of the month has been removed due to the large spikes that occur on these days in the testing period. In addition, we eliminate the first day of October, as Eurex Repo only adapts its haircuts one day after the ECB. Thus, we run the following regression:

$$y_t = \beta_0 + \beta_1 newhaircuts_t + \beta_2 endmp1_t + \beta_3 endmp2_t + \varepsilon_t, \tag{1.41}$$

where y denotes the collateral spread, i.e. the Eonia-GCP ECB rate or Eonia-GCP ECB Ext. rate. *newhaircuts*, the variable of interest, is a dummy variable that is equal to one starting on October 2, when the new haircuts are applied by Eurex Repo. We control for the last day of the maintenance period, *endmp1* and *endmp2*.[27]

[**insert Table 1.9 about here**]

Table 1.9 shows the results. The left column displays the results for the two spreads directly affected by the change in haircuts, and the second column those whose liquidity is potentially impacted by the change in ECB haircuts. As hypothesized, the collateral spread for the GCP ECB basket falls by 1.46 bps. For the GCP Extended basket it falls by 1.29 bps. Both effects are significant at the 5% level. Over time this effect weakens, as other factors impacting the collateral spread may change and therefore also the spread. In the period of four weeks around the change in haircuts, the coefficient on *newhaircuts* in the ECB basket regression is -1.00, and in the Extended basket regression it is -1.10. Both coefficients stay highly significant.

The effect on the collateral spreads is in line with our theory. That is a compelling result, which confirms our prediction that the collateral spread is a function of haircuts. This is intuitive. In our model, as haircuts fall, the cash provider has to give more cash

[27]In this period, we do not observe strong maintenance calendar day effects, so we only control for the last day of the maintenance period.

than before for the same security, so that he needs to raise more cash himself in the unsecured and cash market, raising his costs. Thus, repo rates increase relative to the unsecured rate, yielding a lower collateral spread.[28]

1.4.4 Empirical test – Volatility

In our model the collateral spread depends negatively on the volatility of the risk-adjusted return of the underlying repo security, σ_y^2. A higher volatility translates into a larger risk-adjusted return $\hat{y}(\cdot)$, which makes trading in the cash market, the home-made repo transaction, less attractive for the short, so that she is willing to accept a higher repo rate, which decreases the collateral spread. Stated in reverse, if volatility decreases, the collateral spread increases.

The return of the underlying security and its volatility are tied to the current interest rate level, which is decided upon by the ECB. Decisions on monetary policy are made by the governing council, whose members meet twice within a maintenance period. In the last meeting they decide on changes in monetary policy stance, such as the level of interest rates.[29] Before this meeting the uncertainty about changes in monetary policy is naturally higher than on the day of the governing council, when this uncertainty resolves. This uncertainty translates into a higher volatility of returns on the day before the meeting than on the day of the meeting itself. This is shown by Brenner, Pasquariello, and Subrahmanyam (2009), who find that return volatility increases before the announcement of macroeconomic news. Our test builds on this presumption. The dependent variable is the change in the collateral spread from the previous day to today, i.e. Eonia–GCP ECB$_t$–Eonia–GCP ECB$_{t-1}$. In our regression we differentiate between the meeting days where the policy rate is subject to changes and those where it is not. Thus, we run four tests based on the following regression model:

$$\begin{aligned}\Delta y_t =& \beta_0 + \beta_1 govcouncil\_mp_t + \beta_2 govcouncil\_nonmp_t + \beta_3 vstoxx_{t-1} \\ &+ \beta_4 excessliq_{t-1} + X_t\gamma + \varepsilon_t,\end{aligned} \tag{1.42}$$

where Δy_t denotes the change in the collateral spread, Eonia–GCP ECB rate (Δ*collspread1*), and Eonia–GCP ECB Extended rate (Δ*collspread2*). The dummy variable *govcouncil_mp*

[28]In longer-term repos, a lower collateral spread might also be due to a risk adjustment. Haircuts provide a protection against movements in collateral values. Ideally, movements in collateral value never exceed the haircut. However, if haircuts fall, ceteris paribus, there is a higher chance that the haircut cannot fully absorb movements in collateral value. Thus repo rates rise, yielding a lower collateral spread, in order to adjust for this higher risk. This is not relevant in our scenario, as we deal with overnight repo transactions, which are cleared by a CCP.

[29]The dates of those meetings are determined by the ECB one year in advance.

is equal to one, when the governing council meeting involves a potential interest rate change. The dummy variable *govcouncil_nonmp* captures the effect, if there is no potential interest change discussed in the governing council meeting. *vstoxx* is the VSTOXX lagged by one day. *excessliq* is the excess liquidity measured as the sum of volumes at the ECB deposit facility plus current accounts minus volumes at the lending facility, and minus reserve requirements, lagged by one day. As further control variables, which are not shown, we include $perc10|endres$ and $perc90|endres$, as defined in Section 1.4.2 above, the first and last day of each month, and a dummy variable for the financial crisis (equal to one starting on August 07, 2007).

Since there are strong reactions in unsecured and repo rates due to ECB unconventional policies according to Szczerbowicz (2015), we add further variables in our second test to control for the impact of these announcements and implementations. Following her approach, we control for settlement days of the first one-year LTRO (*oneyearltro*) on June 25, 2009, and both three-year LTROs (*3yearltros*) on December 22, 2011 and March 01, 2012, the introduction of a zero deposit facility rate (*zerorate*) on July 11, 2012, the introduction of full allotment on October 09, 2008 (*fullallot*), and the announcement days of ECB unconventional monetary policies.[30]

In our third test we isolate the volatility from the yield effect ($\bar{y}$). A change of the interest rate, if unanticipated, shifts $\bar{y}$, impacting our dependent variable, the change in the collateral spread. Brand, Buncic, and Turunen (2010) show that short-term news by the ECB, such as interest rate decisions, have a significant impact on the yield curve, especially at the short end. So in order to single out the volatility effect, we therefore eliminate the days, when a change of the key policy rate is actually decided.[31] The reason for removing these observations rather than using an additional variable is that on several of these days, in addition to a change in the interest rate, other unconventional monetary policy decisions are announced, e.g. the first covered bond purchase programme (May 07, 2009), for which we already control in our regression.

As monetary policy decisions by the governing council are announced at noon, we take this timing into account in our fourth test. We have intraday repo transactions data, so that we can split observations on days of meetings on monetary policy into the period

[30] The announcement days, which are not reported, involve news on EFSF/ESM, i.e. May 10, 2010, March 14, 2011, and March 26, 2011. Further, they include announcement of covered bond purchase programmes, on May 07, 2009, October 06, 2011 and September 04, 2014. The implementation of very long-term LTROs, one-year and three-year, is made public on May 07, 2009, and December 08, 2012. The announcement of Quantitative Easing involves the days September 04, 2014, and January 22, 2015. For a detailed description of these ECB unconventional monetary policies, please refer to Szczerbowicz (2015).

[31] The key policy rate is the Minimum Bid Rate, even though the effective policy rate after full allotment is the deposit facility rate.

before and after the announcement. The collateral spread should only be affected after the announcement at 13:45 CET (press release on ECB webpage). So when we calculate the volume weighted average repo rate, we only use transactions concluded after 13:45 CET, when these governing council meetings on monetary policy occur.

[insert Table 1.10 about here]

Table 1.10 shows the results. Our main variable of interest, *govcouncil_mp*, clearly impacts the collateral spread, Eonia–GCP ECB rate, at the 5% significance level. It rises by 0.64 bps on the day of governing council meetings, in which they decide on monetary policy, as uncertainty resolves and volatility of bond returns decreases. This effect remains present at a similar magnitude, when including the controls for unconventional monetary policies, and also when removing days with an announcement of interest rate changes. Thus, the GCP ECB collateral spread generally increases. When we restrict data to transactions occurring after 13:45 CET on days including potential changes in monetary policy, the effect of *govcouncil_mp* on Eonia–GCP ECB rates shoots up, to 2.17 bps, nearly three times as large as the effect estimated in the other tests.[32] We also carry out this test, to check for the importance of timing, with the sample of transactions that occur before 13:45. Indeed, then the effect is not statistically from zero. So, this provides strong evidence that lower uncertainty and volatility in bond returns after this announcement are the reason for an increase in the collateral spread. As we have removed days that include a decision for an actual interest rate change, the risk-adjusted mean return $\bar{y}$ should be unaffected in this test.

Interestingly, the collateral spread of the GCP ECB Extended basket is never statistically different from zero, in spite of resilient results for the collateral spread of the GCP ECB basket. A potential explanation can be obtained from our formulas of the collateral spread, (1.35), (1.36), (1.37), or (1.38). We can see in these formulas that the effect of a change in σ_y^2 also depends on the size of the other parameters. For example, in (1.35) the volatility is multiplied by $(1 - \varepsilon_0)$, which is presumably smaller for the GCP ECB Extended basket due to its larger average pricing error (ε_0) than the pricing error of the GCP ECB basket. Thus, the effect on the GCP ECB Extended is potentially lower, if the change in the volatility of returns is similar for both baskets. The impact on the GCP ECB basket clearly exists, in line with our prediction.

Overall we find solid support for our prediction that the collateral spread rises, if the volatility of returns decreases. This result is robust for the collateral spread of the more liquid basket, GCP ECB basket, but not present in the other basket, which can be explained by using our theory.

[32]The number of observations drops, as there are some governing council meeting days on monetary policy, in which no trades occur after 13:45 CET.

1.5 Development of the collateral spread

Having established that our theory holds up to empirical tests, we next employ it to analyze the development of the collateral spreads (in Figure 1.1) over time, i.e. from January 01, 2007 to June 30, 2015. Since there are several events that affect these collateral spreads in this time period, as can be seen in Figure 1.1, the analysis of their development provides important insights. We use the events, which are linked to the financial crisis and ECB monetary policy, to split the time period into eight subperiods, for which we individually provide descriptive statistics (reported in Table 1.11).[33] Our subperiods are defined as follows:

- pre-crisis (Jan 01, 2007 – Jul 31, 2007),
- early crisis (Aug 01, 2007 – Oct 08, 2008),
- start of full allotment (Oct 09, 2008 – Jun 24 2009),
- first one-year LTRO by the ECB (Jun 25, 2009 – Jul 01, 2010),
- start of sovereign problems (Jul 07, 2010 – Dec 21, 2011),
- three-year LTROs (Dec 22, 2011 – Jun 30, 2013),
- one-third of LTROs repaid early (Jul 01, 2013 – Jan 21, 2015) and
- the period after the announcement of the Public Sector Purchase Programme (PSPP) by the ECB (Jan 22, 2015 – Jun 30, 2015), which constitutes the largest programme within its Quantitative Easing programme.[34]

The development of the collateral spreads depends strongly on the Eurosystem monetary policy. Four subperiods are the most interesting ones, as they display key changes in the collateral spreads: the first stage of the crisis, full allotment, and the introduction of the one-year and three-year LTROs. In the early period of the crisis, during which the ECB still operates with a liquidity neutral policy, the average collateral spread Eonia–GCP ECB rate drops to -3 bps, and the spread is primarily negative. The liquidity neutral policy stops with the introduction of the full allotment policy, when the ECB injects as much liquidity to banks as they demand, which has a strong positive effect on the collateral spread Eonia–GCP ECB, its mean rising to 11.7 bps. However, the collateral spread of the GCP ECB Extended basket trades primarily negative with 57% negative days. This is the period with the largest volatility in both collateral spreads (standard

[33]The GCP ECB Extended basket can only be observed starting in our third subperiod.

[34]LTRO is short for long-term refinancing operation by the ECB, and has originally a term of three months. During the course of the financial crisis, the Eurosystem allocates funding with longer terms, the most important ones being one year and three years.

deviation of 8.86 and 9.41 bps). The liquidity injected in the first one-year LTRO, which settles on June 25, 2009, strongly impacts the spread Eonia–GCP ECB Extended rate, lifting the mean to 2.9 bps.[35] Similarly to the one-year LTRO, liquidity allocated in both three-year LTROs raises also both collateral spreads.[36] There are nearly no negative days in the collateral spread of the GCP ECB basket, and the lowest percentage of 3.88% for the spread of the GCP ECB Extended basket.

As we can see, there are primarily two periods, in which the collateral spread is negative, the first stage of the crisis, and, in the case of the GCP ECB Extended basket, the period of full allotment before the first one-year LTRO. In the first stage of the crisis, the negative collateral spread implies that banks short of liquidity face their constraints of borrowing, η and κ, in the unsecured market. This can have two reasons: either they have higher demand for interbank market liquidity, thus hitting their constraint, or, which is more likely, borrowing limits in the unsecured market are reduced as a reaction to the uncertainty about the financial standing of counterparties. Lower η and κ raises the necessary and sufficient conditions (1.26) and (1.27) for observing a negative collateral spread (Theorem 2). The policy of full allotment helps to alleviate the constraints due to these borrowing limits for banks trading in the GCP ECB basket (which is a subset of eligible securities at the Eurosystem), by giving them an additional alternative to borrow liquidity. So the borrowing limits in the unsecured market, η and κ, do not bind anymore. Banks can obtain as much liquidity as they need from the Eurosystem against their collateral. This means, $\hat{y}(\cdot)$ supposedly falls, as risk aversion and volatility drop substantially. This reduces necessary conditions (1.18) and (1.20) for a positive collateral spread (Theorem 1). In short, securities prices rise, and risk-adjusted returns fall. Surprisingly, the other collateral spread, Eonia–GCP ECB Extended rate, stays negative (even though these securities are also eligible), indicating that banks trading in this basket are still constrained by their limits in the unsecured market. Given the fact that the collateral spread of the GCP ECB Extended basket is lower, it indicates that banks use securities as collateral, which are not eligible in the GCP ECB basket, and who are considered to be riskier, resulting in lower borrowing limits in the unsecured market. The implementation of the one-year LTRO, however, leads to positive collateral spreads in both baskets.

Developments in the collateral spread, which at first may seem counterintuitive, now make sense when using our theory. We motivated our paper with reference to the puzzle of negative collateral spreads. Our theory says (roughly) that this may occur when the

[35]This is the first LTRO that provides banks with central bank funding of one year. Banks receive EUR 442 billion in this LTRO.

[36]The ECB implemented two three-year LTROs on December 22, 2011 and March 1, 2012. Banks obtain credit of about EUR 1 trillion.

unsecured rate drops below the adjusted rate of return in the securities market. This may happen as a result of conditions in the unsecured market. It may also occur if securities prices drop so that their adjusted rate of return rise. Thus, negative collateral spreads may be a function of depressed securities prices. As for full allotment, this explanation can be applied to the liquidity supplied in the LTROs. Woschitz (2017) shows that due to the implementation of the three-year LTROs, securities prices strongly increased and yields fell. Thus, according to our theory the adjusted rate of return in the cash market fell and so repo rates followed suit (fell) (as can be seen in Figure 1.1).

1.6 Conclusion

In this paper we offer a theory on the determinants of the repo rate and the collateral spread. Moreover, we give an explanation to the puzzle of the negative collateral spread. The collateral spread can turn negative in two main scenarios. The first one is that the unsecured rate falls to a large extent, which occurs at the end of the maintenance period, as we have shown in our spikes test. The second scenario is that securities prices fall, so that risk-adjusted cash market returns increase. The condition for these two scenarios to be possible is that the cash provider is more constrained than the short in the unsecured market.

Our model, while explaining the possibility of a negative collateral spread, offers several additional insights. The basis for this model is the conjecture that the short has two options, the combination of repo trade and unsecured borrowing, and the combination of securities cash market trades and unsecured borrowing, where the latter alternative is a home-made repo. In addition, we abstract from credit risk, thus showing that the relationship between the unsecured rate, repo rate, and risk-adjusted return is driven by other factors. We discover that the collateral spread is a function of haircuts, bond return volatility, pricing errors, and potentially of the borrowing limits of the short and the cash provider. Two tests, which we run ourselves by using data on the European unsecured overnight rate, Eonia, and repo transactions data, confirm the positive relationship of the collateral spread to haircuts (if the collateral spread is positive), and the inverse relationship to volatility. This support for our theory by empirical tests thus enables us to provide explanations for the development of the collateral spread over time.

This is the first model to the best of our knowledge that uncovers the determinants of the collateral spread. One of its main insights is that repo and unsecured rates as well as risk-adjusted cash market returns are coupled to each other. This model provides the foundation for further tests on the collateral spread, thus yielding a better understanding of the behavior of interbank market rates.

1.7 Appendix

1.7.1 Proofs

Proof of Theorem 1

The proof starts by considering the upper and lower bounds on r as given by (1.14) and (1.17), respectively. As seen, these are functions of Ω and A, respectively. The expression (1.12) for Ω and the expression (1.16) for A show that these depend on the magnitude of $u - \bar{y}$. There are four cases to consider, as listed below. The proof proceeds by going through these four cases in order. In doing this, the bounds on $\hat{y}(\cdot)$, (1.18) and (1.20), as necessary conditions for $r \leq u$, and the formulas for r in items 1–3 in the statement of the theorem will be established. The proof ends by establishing sufficient conditions for $r \leq u$ when $\eta \leq \kappa$ and $\eta > \kappa$.

Case 1, $u - \bar{y} \geq \rho\sigma_y^2(1 - \varepsilon_0)$:
The expression for r, (1.21), follows directly from (1.12), (1.14), (1.16), and (1.17). All that remains is to verify that $r \leq u$. Now, (1.21), implies that $r \leq u$ if and only if $(1 - \varepsilon_0)\hat{y}(1) + \varepsilon_0 u \leq u$, which, in turn, holds if and only if $\hat{y}(1) \leq u$ (since $\varepsilon_0 \in [0, 1)$). Thus, using (1.4), we have that $r \leq u$ if and only if $\bar{y} + \rho\sigma_y^2(1 - \varepsilon_0)/2 \leq u$, which holds by assumption (Case 1).

Case 2, $\rho\sigma_y^2 \max\{1 - \eta, 1 - \kappa\} \leq u - \bar{y} < \rho\sigma_y^2(1 - \varepsilon_0)$:
The first equality in (1.22) follows from (1.12), (1.14), (1.16), and (1.17). The second equality follows by substituting in the expression in (1.9) for ω^*. From the final expression in (1.22), it is immediate that $r \leq u$ holds.

Case 3, $\eta \leq \kappa$ and $u - \bar{y} < \rho\sigma_y^2(1 - \eta)$:
We will start with the upper bound of r. Since $u - \bar{y} < \rho\sigma_y^2(1 - \eta)$, (1.12) implies that $\Omega = (1 - \eta)/(1 - \varepsilon_0)$. Substituting this into the upper bound for r, as given by (1.14), we have the first expression in (1.23). The second expression follows by substituting in the expression for $\hat{y}((1 - \eta)/(1 - \varepsilon_0))$ using (1.4) with $\omega = (1 - \eta)/(1 - \varepsilon_0)$. Next, we ask whether $\bar{r} \leq u$. From (1.23), this is true if and only if $\hat{y}((1 - \eta)/(1 - \varepsilon_0)) \leq u$. This is equivalent to saying $\bar{y} + \rho\sigma_y^2(1 - \eta)/2 \leq u$. Thus, if this is not met, the maximum r is given by u, so that, in general, the upper bound on r is $\min\{u, \bar{r}\}$. In particular,

$$\min\{u, \bar{r}\} = \begin{cases} \bar{r} & \text{if } \rho\sigma_y^2(1 - \eta) > u - \bar{y} \geq \rho\sigma_y^2(1 - \eta)/2 \\ u & \text{if } u - \bar{y} < \rho\sigma_y^2(1 - \eta)/2. \end{cases} \tag{1.43}$$

Next we consider the lower bound on r. This is given by (1.17). Substituting in the values of A from (1.16), we get the expressions for $\underline{r}$ in (1.24). It is obvious that $\underline{r} < u$ when $u - \bar{y} \geq \rho\sigma_y^2(1-\kappa)$. Consider next the case that $u - \bar{y} < \rho\sigma_y^2(1-\kappa)$. Proceeding as above, we have that $\underline{r} \leq u$ if and only if $\bar{y} + \rho\sigma_y^2(1-\kappa)/2 = \hat{y}((1-\kappa)/(1-\varepsilon_0)) \leq u$. Note that this also gives rise to the bound (1.18).

To complete the proof of item 3 of the theorem as well as the bound (1.18), we need to show that $\underline{r} < \min\{u, \overline{r}\}$ whenever $\min\{u, \overline{r}\} = \overline{r}$, that is, whenever $\rho\sigma_y^2(1-\eta) > u - \bar{y} \geq \rho\sigma_y^2(1-\eta)/2$.

There are two cases to consider:

Case (a): $1 - \kappa \leq (1-\eta)/2$.
In this case, we need to show that[37]

$$u - \frac{1}{2}\frac{(u-\bar{y})^2}{\rho\sigma_y^2(1-h)} \leq \frac{(1-\eta)\left(\bar{y} + \frac{1}{2}\rho\sigma_y^2(1-\eta)\right) + (\eta - h)u}{1-h} \tag{1.44}$$

for $\rho\sigma_y^2(1-\eta) > u - \bar{y} \geq \rho\sigma_y^2(1-\eta)/2$. Condition (1.44) simplifies to

$$\frac{1}{2\rho\sigma_y^2(1-\eta)}(u-\bar{y})^2 - (u-\bar{y}) + \frac{\rho\sigma_y^2(1-\eta)}{2} \geq 0.$$

Define the function $f(x) = \frac{1}{2a}x^2 - x + \frac{a}{2}$, where a is a constant. We need to show that $f(x) \geq 0$ for $x \leq a$. It is easy to verify that the unique zero of $f(x)$ occurs at $x = a$. Furthermore, $f'(x) < 0$ for $x < a$, $f'(x) > 0$ for $x > a$, and $f''(x) > 0$. Thus, $f(x) > 0$ for $x < a$. This implies that (1.44) is satisfied for $\rho\sigma_y^2(1-\eta) > u - \bar{y} \geq \rho\sigma_y^2(1-\eta)/2$.

Case (b):$1 - \kappa > (1-\eta)/2$.
In this case, (1.44) needs to hold for $\rho\sigma_y^2(1-\eta) > u - \bar{y} \geq \rho\sigma_y^2(1-\kappa)$, which it does by the same argument we just have gone through. In addition, we must have $\underline{r} \leq \overline{r}$ for

$$\frac{u-\bar{y}}{\rho\sigma_y^2} \in \left[\left(\frac{1-\eta}{2}\right), 1-\kappa\right). \tag{1.45}$$

Using (1.12), (1.14), (1.16), and (1.17)), this condition can be written

$$(1-\kappa)\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) + \kappa u \leq (1-\eta)\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) + \eta u. \tag{1.46}$$

Using the definition of $\hat{y}(\cdot)$ in (1.4), (1.46) simplifies to

$$\frac{u-\bar{y}}{\rho\sigma_y^2} \leq \frac{1}{2}\frac{(1-\eta)^2 - (1-\kappa)^2}{\kappa - \eta}. \tag{1.47}$$

[37]The left hand side of (1.44) is $\underline{r}$ when $u - \bar{y} \geq \rho\sigma_y^2(1-\kappa)$ as derived above and stated in (1.24). The right hand side is $\overline{r}$ for $u - \bar{y} \geq \rho\sigma_y^2(1-\eta)/2$ as derived above and stated in (1.23).

Setting $(u - \bar{y})/(\rho\sigma_y^2)$ equal to $(1 - \kappa)$, the least upper bound from (1.45), we have, after some algebra, that (1.47) holds if $(\eta - \kappa)^2 > 0$. Hence, $\underline{r} < \overline{r}$ on the interval in (1.45). Thus, we have proved that the claim in item 3 of the theorem as well as the bound (1.18) as a necessary condition of $r \leq u$ when $\eta \leq \kappa$.

Case 4, $\boldsymbol{\kappa < \eta}$ and $\boldsymbol{u - \bar{y} < \rho\sigma_y^2(1 - \kappa)}$:
Note that in this case, $A = (1 - \kappa)/(1 - \varepsilon_0)$ by (1.16).

Suppose first that $u - \bar{y} \leq \rho\sigma_y^2(1 - \eta)$ so that $\Omega = (1 - \eta)/(1 - \varepsilon_0)$. An equilibrium repo rate only exists if the upper bound, (1.14), is larger than the lower bound, (1.17). That is, if

$$\frac{(1-\eta)\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) + (\eta - h)u}{1-h} \geq \frac{(1-\kappa)\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) + (\kappa - h)u}{1-h}. \tag{1.48}$$

This yields (1.46) once again. Since $\eta > \kappa$, this, in turn, can now be written as

$$\frac{u - \bar{y}}{\rho\sigma_y^2} \geq \frac{1}{2}\frac{(1-\kappa)^2 - (1-\eta)^2}{\eta - \kappa}. \tag{1.49}$$

Since $(u - \bar{y})/\rho\sigma_y^2 \leq (1 - \eta)$, (1.49) does not hold. Thus, there is no equilibrium repo rate, $r \leq u$, when $u - \bar{y} < \rho\sigma_y^2(1 - \eta)$.

Suppose next that $u - \bar{y} > \rho\sigma_y^2(1 - \eta)$ so that $\Omega = \omega^*$ as given by (1.9). The short is unconstrained and the upper bound, therefore, is

$$\overline{r} = u - \frac{1}{2}\frac{(u - \bar{y})^2}{\rho\sigma_y^2(1-h)}.$$

Thus, for there to be an equilibrium repo rate, we must have $\overline{r} \geq \underline{r}$, which is

$$u - \frac{1}{2}\frac{u - \bar{y}}{\rho\sigma_y^2(1-h)} \geq \frac{(1-\kappa)\left(\bar{y} + \frac{1}{2}\rho\sigma_y^2(1-\kappa)\right) + (\kappa - h)u}{1-h}. \tag{1.50}$$

This becomes after some algebra

$$(u - \bar{y})^2 - 2\rho\sigma_y^2(1-\kappa)(u - \bar{y}) + \rho^2\sigma_y^4(1-\kappa)^2 \leq 0, \tag{1.51}$$

or,

$$(\rho\sigma_y^2(1-\kappa) - (u - \bar{y}))^2 \leq 0, \tag{1.52}$$

which is not possible (because $\rho\sigma_y^2(1 - \kappa) \neq (u - \bar{y})$). Hence, there is no equilibrium repo rate in Case 4. This establishes the bound (1.20) as a necessary condition for $r \leq u$ when $\eta > \kappa$.

Sufficient conditions for $r \leq u$

We now turn to showing that the bounds (1.19) and (1.20) are sufficient conditions for $r \leq u$ when $\eta \leq \kappa$ and $\eta > \kappa$, respectively.

Consider first the case that $\eta > \kappa$ and assume that (1.20) holds, that is, $u - \bar{y} \geq \rho\sigma_y^2(1-\kappa)$. We claim this implies $r \leq u$. The construction in the text and in the proof above demonstrates that there is an equilibrium repo rate $r \leq u$. We need to show that the converse is not possible. Therefore, suppose, by contradiction, that $r > u$. Thus, under the repo alternative (Alternative 1), the short optimally chooses to borrow η and, therefore, repo the fraction

$$\phi = \frac{1-\eta}{1-h} \tag{1.53}$$

of her security. Under Alternative 2, the short cannot do worse than choosing $\omega = (1-\eta)/(1-\epsilon_0)$ and borrowing η at the unsecured rate. Therefore, along the same lines as in the derivation of (1.13), for the short to be willing to do a repo, we must have

$$(1-\eta)r + \eta u \leq (1-\eta)\hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) + \eta u \tag{1.54}$$

which reduces to

$$r \leq \hat{y}\left(\frac{1-\eta}{1-\varepsilon_0}\right) = \bar{y} + \frac{\rho}{2}\sigma_y^2(1-\eta). \tag{1.55}$$

However, by $\eta > \kappa$ and (1.20), we also have

$$\bar{y} + \frac{\rho}{2}\sigma_y^2(1-\eta) < \bar{y} + \rho\sigma_y^2(1-\kappa) \leq u. \tag{1.56}$$

Combined with (1.55), this implies $r < u$, which is a contradiction. Hence, when $\eta > \kappa$, (1.20) implies $r \leq u$.

Consider next the case that $\eta \leq \kappa$ and assume that (1.19) holds, that is, $\hat{y}((1-\eta)/(1-\varepsilon_0)) \leq u$. We claim this implies $r \leq u$. Suppose, by contradiction, that $r > u$. As above, this leads to (1.55). But this contradicts (1.19). Hence, when $\eta \leq \kappa$, (1.19) implies $r \leq u$. $\square$

Proof of Theorem 2

Case 1, $\boldsymbol{\eta \leq \kappa}$:
Necessary condition: By Theorem 1, $r > u$ implies (1.26), or $u - \bar{y} \leq \rho\sigma_y^2(1-\eta)/2$. Thus, we assume that this holds. From (1.29) we see that $\overline{r}_{neg} > u$. We need to check that the two parties are wiling to enter a repo, i.e. $\underline{r}_{neg} \leq \overline{r}_{neg}$. There are two cases to consider.

Case (a): $1 - \kappa \geq (1-\eta)/2$.
In this case, by (1.30), $A = (1-\kappa)/(1-\varepsilon_0)$. By (1.32), the minimum acceptable rate to the cash provider is, therefore,

$$\underline{r}_{neg} = \frac{(1-\kappa)\hat{y}\left(\frac{1-\kappa}{1-\varepsilon_0}\right) + \kappa u - \eta u}{1-\eta} \tag{1.57}$$

Since we also have $u - \bar{y} < \rho\sigma_y^2(1-\eta)$, combining (1.57) with the maximum the short is willing to pay, as given by (1.29), we once again obtain condition (1.46) from the proof of Theorem 1 (Case 3). Since $(u-\bar{y})/\rho\sigma_y^2 \leq 1-\kappa$, the same proof as in Theorem 1, Case 3, applies, establishing that (1.46) holds. In other words, $\underline{r}_{neg} \leq \overline{r}_{neg}$. It is easy to check that $u \leq r_{neg}$ so that any repo rate in the interval $(r_{neg}, \overline{r}_{neg}]$ is consistent with equilibrium $r > u$.

Case (b): $1 - \kappa < (1-\eta)/2$.
We need only consider $u - \bar{y} > \rho\sigma_y^2(1-\kappa)$, as the reverse is covered by the argument in case (a). Now, if $A = \omega^*$ as given by (1.9),

$$\underline{r}_{neg} = u - \frac{1}{2}\frac{(u-\bar{y})^2}{\rho\sigma_y^2(1-\eta)}. \tag{1.58}$$

The upper bound, $\overline{r}_{neg}$ is given by (1.29). Comparing these expressions, we have, after some algebra, that $\overline{r}_{neg} \geq \underline{r}_{neg}$ if and only if

$$(\rho\sigma_y^2(1-\eta) - (u-\bar{y}))^2 \geq 0, \tag{1.59}$$

which always holds. This is what we wanted to show. Since $u \leq r_{neg}$, any repo rate in the interval $(r_{neg}, \overline{r}_{neg}]$ is consistent with equilibrium $r > u$.

If $A = \phi = (1-\eta)/(1-h)$, we know from the discussion in the text that we must also have $\varepsilon_0 > h$. So suppose this holds. Using (1.30), the lower bound can be written

$$\underline{r}_{neg} \geq \frac{\frac{1-\eta}{1-h}(1-\varepsilon_0)\hat{y}\left(\frac{1-\eta}{1-h}\right) + \left(1 - \frac{1-\eta}{1-h}(1-\varepsilon_0)\right)u - \eta u}{1-\eta}. \tag{1.60}$$

Using (1.29), $\underline{r}_{neg} \leq \overline{r}_{neg}$, if and only if

$$\frac{1}{2}\rho\sigma_y^2\frac{1-\eta}{1-h}\left[(1-h)^2-(1-\varepsilon_0)^2\right] \geq (\varepsilon_0-h)(u-\bar{y}). \tag{1.61}$$

Rewriting yields the condition

$$u-\bar{y} \leq \rho\sigma_y^2\frac{1-\eta}{1-h}\left(1-\frac{1}{2}(h+\varepsilon_0)\right) < \frac{1}{2}\rho\sigma_y^2(1-\eta), \tag{1.62}$$

which is the necessary condition, (1.26), for a negative collateral spread.
Sufficient condition: By the same argument as in case (a) above, (1.27) implies that $\overline{r}_{neg} \geq \underline{r}_{neg}$ and, therefore, also that there is equilibrium $r > u$.

Finally, note first that the analysis above, and, in particular, (1.57), (1.58), and (1.60), show that $\underline{r}_{neg}$ is given by (1.33). The statement in the theorem follows by $u \leq \underline{r}_{neg} \leq \overline{r}_{neg}$, which is already established in all scenarios above. We also see that $\underline{r}_{neg} = \overline{r}_{neg}$ if and only if $\eta = \kappa$ and these are then given by (1.57), which collapses to the right hand side of (1.34).

Case 2, $\boldsymbol{\eta > \kappa}$:
By Theorem 1, if $\eta > \kappa$, $r > u$ is not possible if $u - \bar{y} \geq \rho\sigma_y^2(1-\kappa)$. Therefore, suppose $u - \bar{y} < \rho\sigma_y^2(1-\kappa)$.

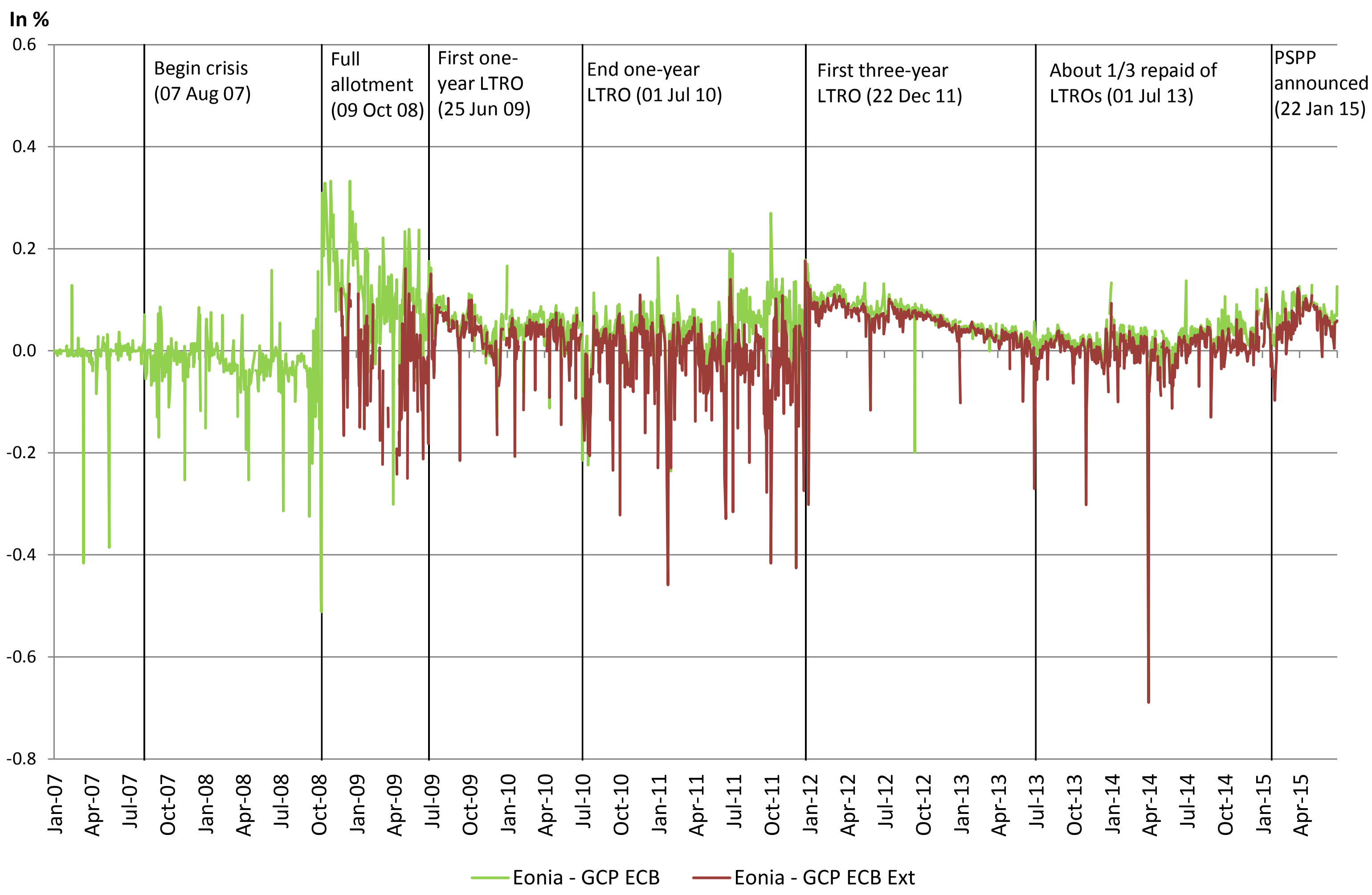
We consider first the case that $(1-\epsilon_0)\phi > 1-\kappa$ so that $A \neq \phi$. Thus, $\underline{r}_{neg}$ is given by (1.57). Suppose now that we also have $u - \bar{y} < \rho\sigma_y^2(1-\eta)$. Then, combining (1.57) with the maximum the short is willing to pay, as given by (1.29), we obtain (1.46). But as already shown in the proof of Theorem 1 (Case 4), this does not hold when $\eta > \kappa$.

Suppose next that $u - \bar{y} > \rho\sigma_y^2(1-\eta)$ so that $\Omega = \omega^*$ as given by (1.9). The exact same argument as in Case 4 of the proof of Theorem 1 now applies and shows that, once again, $\overline{r}_{neg} < \underline{r}_{neg}$. Hence, $r > u$ cannot be equilibrium when $\eta > \kappa$ and $(1-\epsilon_0)\phi > 1-\kappa$.

Last, we consider the case that $(1-\epsilon_0)\phi \leq 1-\kappa$ so that $A = \phi$. The same algebra as in the case of $\eta < \kappa$ shows that a necessary condition for a negative collateral spread is that (1.26) is satisfied. It is straightforward that this is also sufficient. □

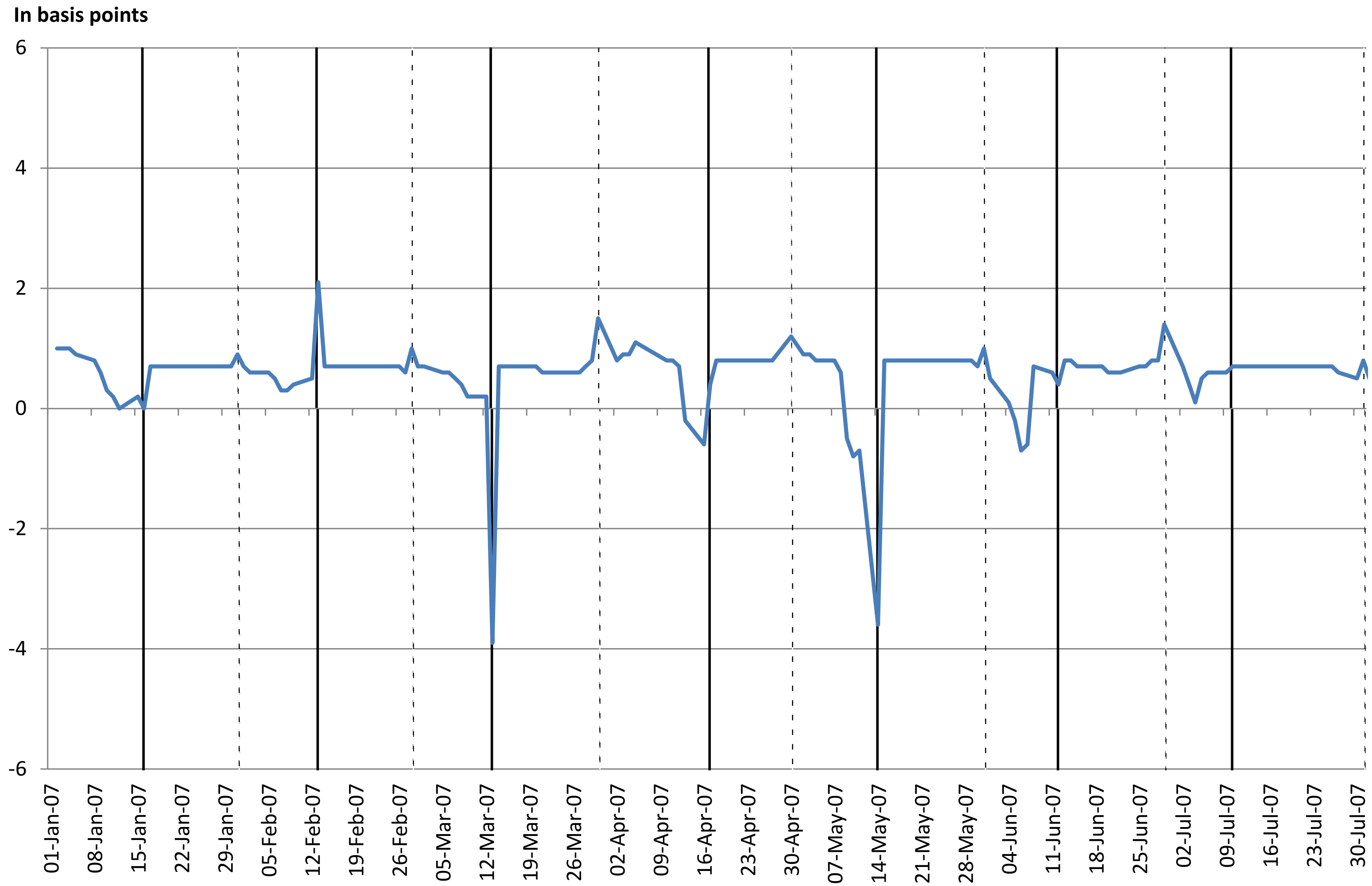
1.7.2 Figures

Figure 1.1: Collateral spread



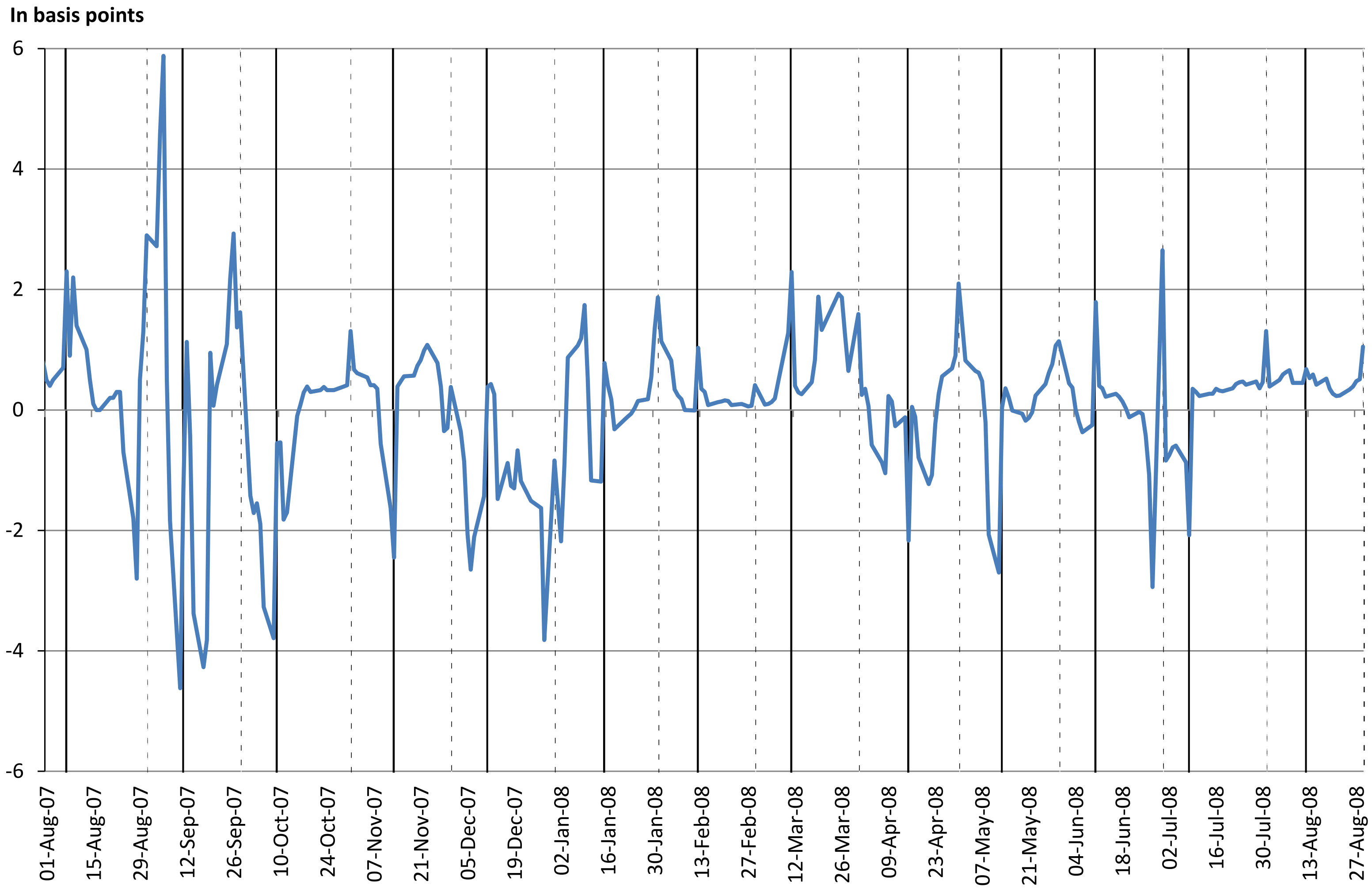
This figure shows the development of the two collateral spreads, Eonia-ECB basket rate and Eonia-ECB Extended basket rate. The repo rates, ECB basket and ECB Extended, are the ON rate. They are the volume-weighted average for each day. The sample period is 01 January 2005 to 30 June 2015.

Figure 1.2: Eonia-MRO I



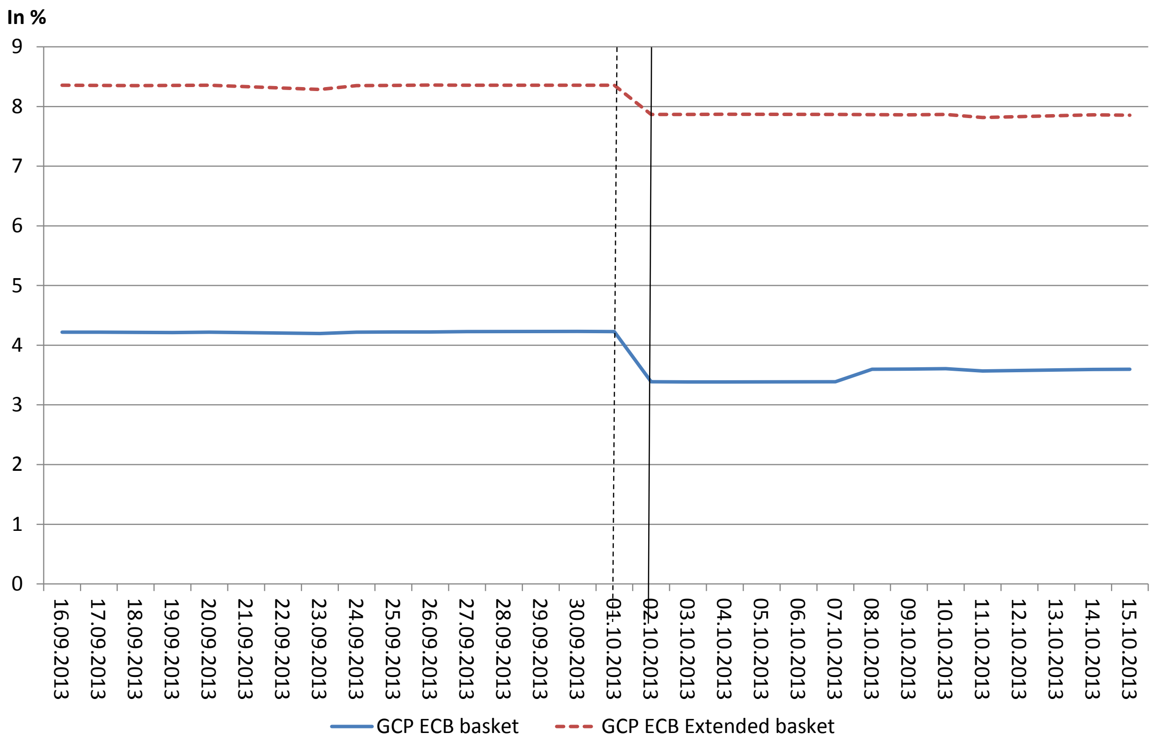
This figure shows the development of the spread Eonia-MRO in the time period January 01 - July 31, 2007. Dotted lines represent the last day of the month, straight lines show the last day of the maintenance period.

Figure 1.3: Eonia-MRO II



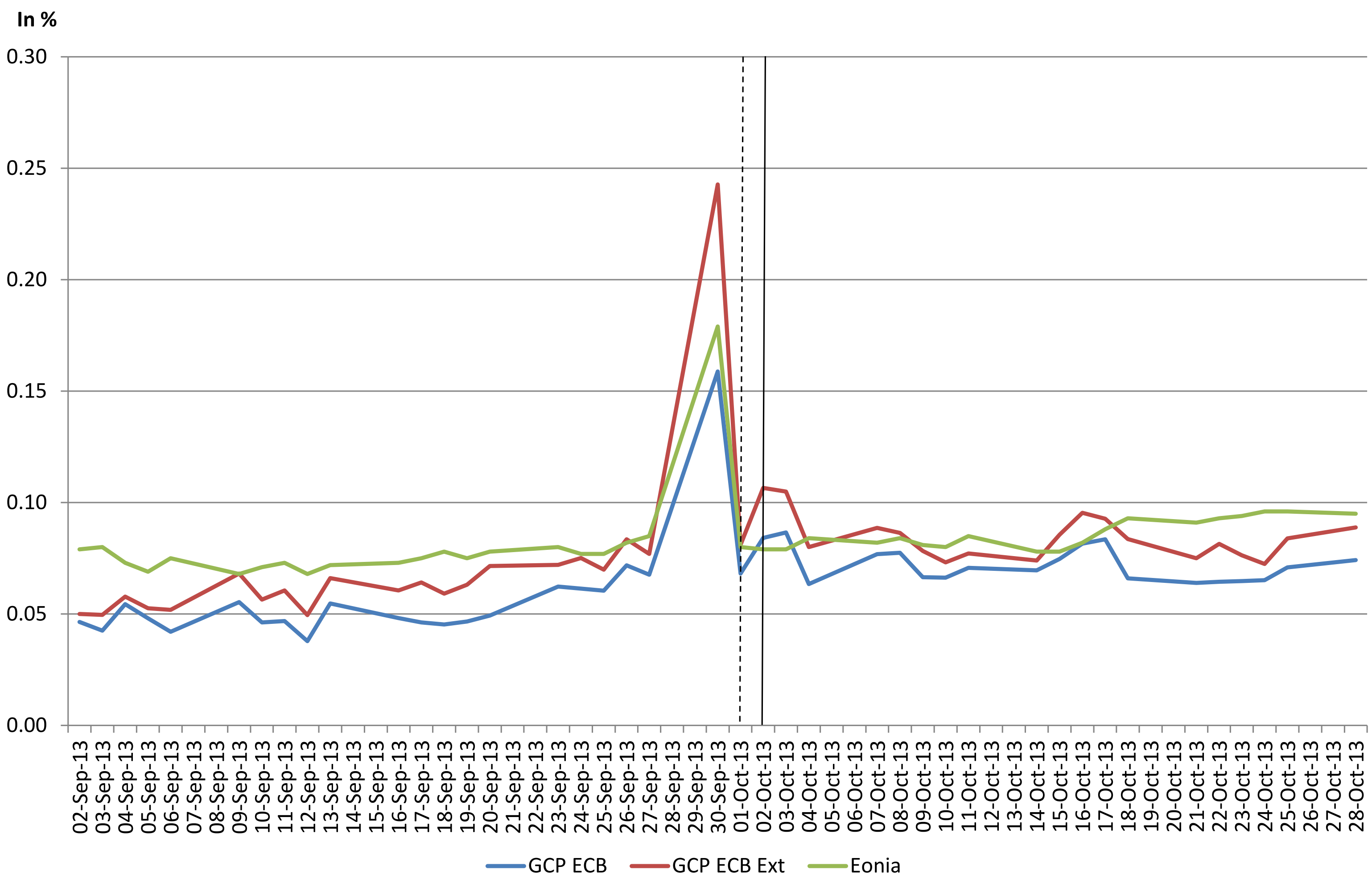
This figure shows the development of the spread Eonia-MRO in the time period August 01, 2007 - August 30, 2008. Dotted lines represent the last day of the month, straight lines show the last day of the maintenance period.

Figure 1.4: Average haircut



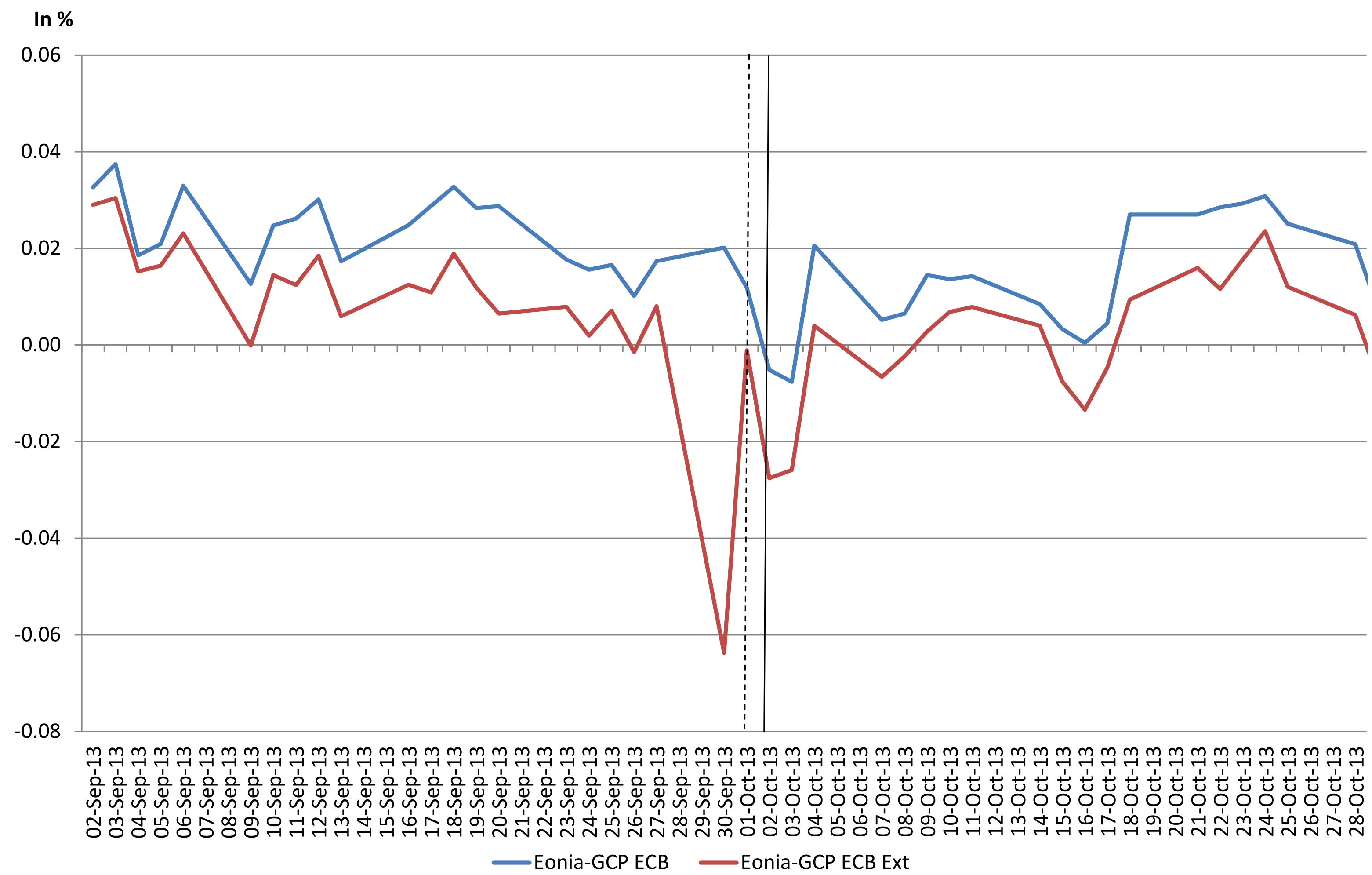
This figure shows the development of the average haircut in the two baskets, GCP ECB and GCP ECB Extended, around the date of change in haircuts. The data ranges from September 16, 2013 to October 15, 2013. From the list of securities in each basket, we calculate the daily average. The day of change by the ECB, October 01, 2013, is marked by the dashed line, the change by Eurex Repo on October 02, 2013, by the black line.

Figure 1.5: Rates



This figure shows the behavior of the Eonia, and the GC Pooling rates around the date of the change in haircuts. The day of the change by the ECB, October 01, 2013, is marked by the dashed line, the change by Eurex Repo on October 02, 2013, by the black line. Repo rates are the daily volume-weighted overnight rates.

Figure 1.6: Collateral spread



This figure shows the behavior of the collateral spreads, Eonia-GC Pooling rate (ECB and ECB Extended), around the date of the change in haircuts. Repo rates are the daily volume-weighted overnight rates. The day of the change by the ECB, October 01, 2013, is marked by the dashed line, the change by Eurex Repo on October 02, 2013, by the black line. Each rate is the volume-weighted average for each day.

1.7.3 Tables

Table 1.1: Statistics on Eurex Repo baskets

This table displays descriptive statistics on the different GC baskets of Eurex Repo for the period January 01, 2005 to June 30, 2015. There are 4 GC Pooling baskets, and 24 Euro Repo baskets. The first columns shows when the first and last trades in that basket occur in our sample. The second column, No. Obs., counts the number of trades in each basket. The third column, ON obs., displays the number of trades with the term overnight. The fourth column, % of total, shows the percentage of the ON transactions of all transactions. The fifth column, TN obs., displays the number of trades with the term tomorrow/next. The sixth column, % of total, is the percentage of the TN transactions of all transactions. The seventh column, Av. Rate, shows the volume-weighted average rate. For the GC Pooling ECB and ECB Ext. basket this is the ON rate, for all others it is the TN rate. The next column, Av. Coll. Spread, displays the volume-weighted collateral spread, Eonia- repo rate, matched for the same term. The rate is the ON rate for the GC Pooling ECB and ECB Ext. rate, and it is the TN rate for all other baskets. The ninth column, Volume - Total, is the sum of the total transacted volume in that basket. The next column, Volume - By Trading Day, shows the average volume by trading day (period that the basket is traded). The last column, Volume - By Transact., captures the average transaction volume in each trade.

							Av. Rate	Av. Coll. Spr.	Volume (in EUR million)		
	first - last trade	No. Obs.	ON obs.	% of total	TN obs.	% of total	(in bps)	(in bps)	Total	By Trading day	By Transaction
GC Pooling ECB	Jan 02, 07 – Jun 30, 15	151,330	83,804	55.38	26,707	17.65	84.05	4.07	87,434,094	40,311	578
GC Pooling ECB Ext.	Nov 24, 08 – Jun 30, 15	67,944	32,846	48.34	15,181	22.34	26.12	1.38	30,908,936	18,333	455
German KfW / Laender	Jan 03, 07 – Sep 14, 12	8,457	0	0.00	3,804	44.98	100.54	-0.42	2,403,894	1,645	284
EIB / KFW	May 25, 11 – Sep 14, 12	2,399	0	0.00	1,701	70.90	42.24	11.43	541,672	1,598	226
KFW	Sep 17, 12 – Jun 30, 15	3,217	154	4.79	2,497	77.62	3.91	2.36	883,928	1,250	275
Euro Covered Bond	Jan 09, 07 – Aug 14, 14	7,474	8	0.11	4,882	65.32	151.19	-6.14	2,415,711	1,243	323
Germany	Jan 09, 07 – Jun 30, 15	3,534	107	3.03	2,054	58.12	67.85	5.28	2,444,870	1,130	692
EIB	Sep 17, 12 – Jun 29, 15	2,869	186	6.48	2,292	79.89	4.45	2.49	783,557	1,110	273
EFSF	Sep 17, 12 – Jun 30, 15	2,129	47	2.21	1,873	87.98	2.91	1.87	422,073	598	198
French Covered Bond	Apr 04, 09 – May 19, 15	4,467	35	0.78	2,792	62.50	40.20	0.84	777,149	496	174
German Jumbo Pfandbrief	Jan 02, 07 – Jul 02, 13	2,045	0	0.00	1,141	55.79	205.38	-1.58	741,682	446	363
German Laender	Sep 18, 12 – Jun 30, 15	865	48	5.55	327	37.80	2.24	3.88	279,568	396	323
Agency	Feb 09, 07 – Dec 17, 14	3,645	4	0.11	1,972	54.10	61.06	-3.35	697,299	347	191
Germany 10 Year	Jan 08, 07 – Jan 06, 15	236	0	0.00	72	30.51	258.23	15.22	679,004	332	2,877
German Corporate	Feb 18, 08 – Dec 17, 12	216	0	0.00	73	33.80	111.47	0.32	102,330	82	474
German Pfandbrief	Mar 06, 08 – Jan 15, 15	206	0	0.00	94	45.63	284.56	-5.58	103,299	59	501
GC Pooling Equity	Mar 16, 11 – Jun 23, 15	153	6	3.92	23	15.03	11.26	-19.44	38,810	36	254
Austrian Government	Dec 14, 12 – Jun 17, 15	77	9	11.69	32	41.56	-4.27	3.93	20,964	33	272
German Gov. Guaranteed	Oct 16, 12 – Sep 04, 14	40	0	0.00	38	95.00	6.05	4.08	8,841	18	221
French Government	Nov 12, 12 – Jun 16, 15	35	4	11.43	6	17.14	3.08	3.62	11,339	17	324
Finnish Government	Apr 22, 13 – Mar 18, 15	18	2	11.11	13	72.22	4.46	5.18	7,884	16	438
GC Pooling INT MXQ	Mar 05, 14 – Sep 26, 14	8	2	25.00	4	50.00	5.25	-3.57	1,840	13	230
Dutch Government	Jan 17, 14 – Jun 26, 15	18	1	5.56	7	38.89	-0.14	3.98	3,920	11	218
European Government	Jan 09, 07 – May 08, 15	150	0	0.00	17	11.33	276.09	-5.55	22,775	11	152
Belgian Government	Sep 27, 12 – Jun 10, 15	39	1	2.56	17	43.59	-0.35	2.50	6,806	10	175
European Corporate	Feb 12, 09 – Feb 19, 14	75	0	0.00	45	60.00	78.51	-8.00	9,674	8	129
Euro Gov. Guaranteed	Nov 14, 12 – Dec 17, 14	11	0	0.00	0	0.00	0.00	0.00	1,426	3	130
Spanish Government	Jun 04, 13 – Apr 14, 15	6	0	0.00	1	16.67	10.00	-1.90	606	1	101

Table 1.2: Descriptive statistics on the collateral spread

This table displays descriptive statistics on the collateral spread in the period January 01, 2007 to June 30, 2015 for the Eonia – GCP ECB rate. The Eonia – GCP ECB Ext. rate is only observable starting on November 24, 2008. The collateral spread is the difference between the Eonia and the volume-weighted repo rate per day. It is measured in basis points.

	No. Obs.	Mean	St. Error	Median	St. Deviation	Min	Max	# negative days	% of neg. days of obs.
Eonia- GCP ECB rate	2,167	3.77	0.15	4.11	6.74	-51.13	33.27	496	22.89%
Eonia- GCP ECB Ext. rate	1,604	1.36	0.17	2.37	6.69	-68.92	17.62	461	28.74%

Table 1.3: Ranks

This table shows the rank of the standardized Eonia on the last five days of the maintenance period, *endmp* to *endmp-4*, and the last day of the month, *monthend*. Eonia is the overnight unsecured interbank rate. The sample period ranges from January 01, 2007 to August 12, 2008, so that the last period covers a full maintenance period. Each period refers to one maintenance period, in total 20. The first one is incomplete, as the corresponding starting date of this maintenance period was on December 13, 2006. *stand. Eonia* is defined as the spread $(Eonia - mean(Eonia)/st.deviation$ (in bps). The calculation of the mean and the standard deviation exclude the last five days of the maintenance period and the last day of the month. The order of ranking is determined by the sign of the collateral spread on the last day of the maintenance period, *endmp*. If it is negative, all values in the maintenance period are ranked in ascending order, starting with the lowest negative value, and vice versa. The same ranking is done for the last day of the month, but uncoupled from the ranking for the last days of the maintenance period, e.g. in case it has the largest positive value, it obtains the first rank. Days in the last week of the maintenance period that have the first rank are marked in bold.

	Period 1		Period 2		Period 3		Period 4	
	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank	stand. Eonia	rank
endmp	**-5.51**	**1**	**23.37**	**1**	**-107.52**	**1**	-2.45	3
endmp-1	-4.27	3	-2.80	17	-11.24	2	**-9.77**	**1**
endmp-2	-5.51	2	-4.44	18	-11.24	3	-6.84	2
endmp-3	-4.27	4	-6.08	19	-6.54	4	-0.26	12
endmp-4	-3.64	5	-6.08	20	-4.19	5	0.47	19
monthend	–	–	3.74	2	7.55	1	5.60	1
	Period 5		Period 6		Period 7		Period 8	
endmp	**-113.47**	**1**	-0.85	5	0.13	13	**28.01**	**1**
endmp-1	-38.96	3	-0.20	7	-0.78	8	0.37	5
endmp-2	-41.53	2	0.13	9	-0.78	7	-3.08	17
endmp-3	-33.83	4	-4.14	2	-1.69	3	-4.81	20
endmp-4	-5.57	5	**-4.47**	**1**	**-5.33**	**1**	-3.08	18
monthend	9.85	1	1.12	1	6.50	1	2.10	2
	Period 9		Period 10		Period 11		Period 12	
endmp	-1.22	5	-0.09	10	**-3.61**	**1**	0.05	9
endmp-1	**-3.29**	**1**	-1.52	3	-2.44	4	-3.03	4
endmp-2	-1.53	3	-1.29	5	-0.92	5	-4.19	2
endmp-3	-0.05	16	-0.68	6	0.38	15	**-5.11**	**1**
endmp-4	3.36	25	-0.53	8	0.46	21	-4.12	3
monthend	1.48	3	0.87	3	1.74	1	0.05	10
	Period 13		Period 14		Period 15		Period 16	
endmp	1.20	5	1.44	4	**24.85**	**1**	**-3.01**	**1**
endmp-1	-0.29	15	-0.67	16	13.20	2	-0.74	6
endmp-2	-0.27	13	-0.65	15	3.86	3	-0.91	5
endmp-3	1.02	6	-0.29	11	0.63	7	-0.45	8
endmp-4	**1.93**	**1**	-0.16	9	-0.06	11	-0.35	9
monthend	-0.02	10	3.14	1	3.17	4	1.16	4
	Period 17		Period 18		Period 19		Period 20	
endmp	-0.06	9	**4.12**	**1**	-2.04	2	3.18	2
endmp-1	**-3.81**	**1**	-1.49	19	-0.67	4	0.70	12
endmp-2	-2.95	2	-1.82	20	-0.36	8	0.70	11
endmp-3	-0.40	7	-1.35	18	-0.39	7	2.96	3
endmp-4	0.54	12	-0.77	12	-0.54	6	2.64	4
monthend	2.75	1	2.33	2	3.32	1	9.96	1

Table 1.4: Descriptive statistics - spikes

This table displays descriptive statistics on the standardized Eonia rate. Eonia is the overnight unsecured interbank rate. The sample period ranges from January 01, 2007 to August 30, 2008. *endmperiod* to *endmperiod-4* denote the last five days of the maintenance period, where *endmp* is the last day. *monthend* refers to the last trading day of the month. The standardized Eonia (*stand. Eonia*) is calculated in the following way. In each maintenance period we compute ($Eonia - mean(Eonia)/st.deviation$ (in basis points), where the mean and the standard deviation exclude the last five days of the maintenance period and the last day of the month. Then we take the average across maintenance periods. The absolute value is defined as the absolute value of the standardized Eonia in each maintenance period. The column *positive* (*negative*) displays the average value, when the standardized Eonia is positive (negative). The column *upspike-total* (*downspike-total*) shows the number of times, when the standardized Eonia is positive (negative). The column *upspike-abs. >2* (*downspike-abs. >2*) displays the number of times, when the absolute standardized Eonia exceeds two, i.e. the standardized Eonia is two standard deviations away from the mean.

		stand. Eonia (in bps)				upspike		downspike	
	No. Obs.	average value	absolute value	positive	negative	total	abs. >2	total	abs. >2
endmp	20	-7.6752	16.3100	9.5942	-21.8047	9	5	11	7
endmp-1	20	-3.5848	5.0124	4.7589	-5.0572	3	1	17	9
endmp-2	20	-4.1806	4.6503	1.5657	-5.1946	3	1	17	8
endmp-3	20	-3.2668	3.7656	1.2470	-4.3953	4	1	16	7
endmp-4	20	-1.4742	2.4150	1.5681	-2.7780	6	2	14	8
monthend	20	3.5834	3.5854	3.7731	-0.0208	19	13	1	0

Table 1.5: Spikes test

This table shows the regressions of the collateral spread, Eonia-ECB GC Pooling ON. The time period January 01, 2007 to August 30, 2008 is studied. The collateral spread, which is the dependent variable, is the daily volume-weighted average spread in basis points. The independent variables are the following. *fincrisis* is a dummy variable that is equal to one from August, 07 2007 onwards. *monthend* is a dummy variable that is equal to one on the last trading day of the month, and is excluded from the following percentile dummies. *perc10* is a dummy variable that takes the value of one, when the Eonia is in the lower 10% percentile in the respective maintenance period. *perc90* takes the value of one, when the Eonia value is in the upper 90% percentile in that maintenance period. The variables *perc10|nonendres* and *perc90|nonendres* are equal to one, when the value of *perc10*, respectively *perc90*, is outside the last five days of the maintenance period. Likewise, the variables *perc10|endres* and *perc90|endres* are equal to one, when the value of *perc10*, respectively *perc90*, is inside the last five days of the maintenance period. Newey-West standard errors with five lags (Greene (2008)) are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Eonia – GCP ECB	Eonia – GCP ECB
constant	-0.2414	-0.0621
	(0.2920)	(0.2574)
perc10	-3.1908**	
	(1.3942)	
perc90	2.3485*	
	(1.3070)	
perc10|nonendres		-0.5564
		(1.3372)
perc90|nonendres		-0.0563
		(0.7500)
perc10|endres		-5.2123**
		(2.1911)
perc90|endres		6.1432***
		(2.3667)
fincrisis	-2.1864***	-2.4688***
	(0.5443)	(0.5211)
monthend	0.9599	0.9643
	(0.8331)	(0.8363)
No. Obs.	422	422
R-Squared	0.0996	0.1443

Table 1.6: Changes in Haircuts

This table shows the changes in haircuts for the different liquidity categories, maturity buckets and ratings. There are five categories: I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities. Changes in haircuts are implemented by the ECB on October 01, 2013.

Bonds rated AAA to A-	Cat I		Cat II		Cat III		Cat IV		Cat V
Time to maturity	fixed	zero	fixed	zero	fixed	zero	fixed	zero	fixed
0-1	0.0	0.0	0.0	0.0	-0.5	-0.5	0.0	0.0	-6.0
1-3	-0.5	0.5	-1.0	0.0	-1.0	0.0	0.0	0.0	-6.0
3-5	-1.0	-0.5	-1.0	-0.5	-2.0	-1.0	0.0	0.0	-6.0
5-7	-1.0	-0.5	-1.0	-0.5	-2.0	-1.5	0.0	0.0	-6.0
7-10	-1.0	-0.5	-1.0	0.0	-2.5	-1.5	0.0	0.0	-6.0
>10	-0.5	-1.5	0.5	-1.5	-2.0	-3.5	0.0	0.0	-6.0
Bonds rated BBB- to BBB+	**Cat I**		**Cat II**		**Cat III**		**Cat IV**		**Cat V**
Time to maturity	fixed	zero	fixed	zero	fixed	zero	fixed	zero	fixed
0-1	0.5	0.5	1.0	1.0	0.0	0.0	-2.0	-2.0	-10.0
1-3	0.5	1.5	-0.5	3.0	-3.0	-3.0	-3.0	-3.0	-10.0
3-5	1.5	2.0	0.0	3.5	-3.0	-3.0	-4.0	-3.0	-10.0
5-7	2.0	3.0	-2.0	1.5	-2.0	-1.5	-2.5	-3.0	-10.0
7-10	2.5	3.5	-1.0	5.0	-2.0	-1.0	-2.0	-2.0	-10.0
>10	2.5	2.5	2.5	4.0	-2.0	-3.0	-2.0	-2.0	-10.0

Table 1.7: GCP ECB basket: distribution of securities

This table displays the distribution of the securities that are included in the GC Pooling ECB basket across the ECB liquidity categories and maturity buckets on September 26, 2013. There are five categories: I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities.

A- to AAA	Liquidity Group				
Years to Maturity	Cat I	Cat II	Cat III	Cat IV	Total
0-1	177	1,103	1,469	132	2,881
1-3	137	444	711	38	1,330
3-5	120	335	522	33	1,010
5-7	99	217	310	20	646
7-10	121	207	274	13	615
> 10	369	170	130	14	683
Total	1,023	2,476	3,416	250	7,165

Table 1.8: GCP ECB Extended basket: distribution of securities

This table displays the distribution of the securities that are included in the GC Pooling ECB Extended basket across the ECB liquidity categories, maturity buckets and ratings on September 26, 2013. There are five categories: I) government securities, II) local and regional government securities as well Jumbo-style supranational/agency bonds, III) corporate, non-Jumbo and financial securities, IV) unsecured bank bonds, V) asset-backed securities.

A- to AAA	Liquidity Group				
Years to Maturity	Cat I	Cat II	Cat III	Cat IV	Total
0-1	291	1,227	1,705	4,682	7,905
1-3	186	487	863	2,996	4,532
3-5	160	373	634	1,911	3,078
5-7	133	244	396	938	1,711
7-10	156	222	376	608	1,362
> 10	446	184	270	252	1,152
Total	1,372	2,737	4,244	11,387	19,740
BBB- to BBB+	Liquidity Group				
Years to Maturity	Cat I	Cat II	Cat III	Cat IV	Total
0-1	12	2	99	265	378
1-3	9	3	69	187	268
3-5	7		68	117	192
5-7	8	1	71	64	144
7-10	10		41	50	101
> 10	39		55	56	150
Total	85	6	403	739	1,233

Table 1.9: Effect of the haircut on the collateral spread

This table shows the results of the analysis of the collateral spread around the change in haircuts, announced on September 27, 2013 and implemented on October 01, 2013. The collateral spread is measured as the difference between the Eonia and the ON repo rate belonging to the Extended basket or the ECB basket (in basis points). Each observation is the daily volume-weighted average spread. The last day of each month was removed in the regressions. We control for the last day of the maintenance period, *endmp1* and *endmp2*. The dummy variable *newhaircuts* captures the effect of the change in haircuts on the collateral spread. It is equal to one starting October 02, 2013. The first day of October was removed. Newey-West standard errors with two lags are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Sep 13, 2013 – Oct 14, 2013	
	Eonia – GCP ECB Ext	Eonia – GCP ECB
constant	0.8187***	2.2052***
	(0.2363)	(0.3398)
newhaircuts	-1.2892**	-1.4612***
	(0.5715)	(0.4116)
endmp2	0.2342	-0.0976
	(0.5739)	(0.3192)
No. Obs.	20	20
R-Squared	0.31	0.47
	Sep 06, 2013 – Oct 21, 2013	
	Eonia – GCP ECB Ext.	Eonia – GCP ECB
constant	0.9693***	2.3025***
	(0.1983)	(0.2489)
newhaircuts	-1.1378**	-1.2005**
	(0.4713)	(0.4372)
endmp1	0.4781**	0.1703
	(0.1983)	(0.2489)
endmp2	-0.0678	-0.4556
	(0.4678)	(0.3990)
No. Obs.	30	30
R-Squared	0.26	0.31
	Aug 29, 2013 – Oct 28, 2013	
	Eonia – GCP ECB Ext.	Eonia – GCP ECB
constant	1.2497***	2.4138***
	(0.2551)	(0.2077)
newhaircuts	-1.0968**	-1.0049**
	(0.4844)	(0.4253)
endmp1	0.1977	0.0589
	(0.2551)	(0.2077)
endmp2	-0.3892	-0.7624*
	(0.4443)	(0.3976)
No. Obs.	40	40
R-Squared	0.21	0.23

Table 1.10: Test – Volatility

This table shows the regression of Δ Eonia – GCP ECB rate (Δ *collspread 1*) and Δ Eonia – GCP ECB Ext. rate (Δ *collspread 2*) on the dummy variable *govcouncil_mp*, which is equal to one if the governing council meeting includes a decision on monetary policy, the dummy variable *govcouncil_nonmp* for the other meetings of the governing council (without an interest rate decision), *vstoxx*, the lagged VSTOXX, and *excessliq* measured as the sum of current accounts and volumes at the deposit facility minus reserve requirements and volumes at the lending facility. As further control variables, which are not shown, we include $perc10|endres$ and $perc90|endres$, as defined above, the first and last day of each month, and a dummy variable for the financial crisis (equal to one starting on August 07, 2007). In the second model, we also control for settlement days of the first one-year LTRO (*oneyearltro*) on June 25, 2009, and both three-year LTROs (*3yearltros*) on December 22, 2011 and March 01, 2012, the introduction of a zero deposit facility rate (*zerorate*) on July 05, 2012, the introduction and implementation of full allotment on October 09, 2008, October 13, 2008 and October 15, 2008 (*fullallot*), and the announcement days of ECB unconventional monetary policies. The announcement days, which are not reported, involve news on EFSF/ESM, i.e. May 10, 2010, March 14, 2011, and March 26, 2011. Further, they include announcement of covered bond purchase programmes, on May 07, 2009, October 06, 2011 and September 04, 2014. The implementation of very long-term LTROs, one-year and three-year, is made public on May 07, 2009, and December 08, 2012. The announcement of QE involves the days September 04, 2014, and January 22, 2015. In the third model, we exclude days, on which an interest rate change is announced. In addition, in the fourth model we only use repo data on monetary policy meetings after 13:45 CET for calculating the collateral spread. The sample period ranges from January 01, 2007 to June 30, 2015. Newey-West standard errors are shown in parentheses. Lags of Newey-West standard errors are determined by $T^{0.25}$ (Greene (2008)), where T denotes the number of days in the sample. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Model 1		Model 2		Model 3		Model 4	
	Δ collspread 1	Δ collspread 2	Δ collspread 1	Δ collspread 2	Δ collspread 1	Δ collspread 2	Δ collspread 1	Δ collspread 2
constant	8.8525	0.5240	9.0460	0.5429	9.0476	0.5716	9.1324	0.6400
	(7.5460)	(0.3859)	(7.5664)	(0.3836)	(7.5642)	(0.3878)	(7.5629)	(0.3970)
govcouncil_mp	0.6398**	0.1145	0.6299**	0.0848	0.5673*	-0.0930	2.1675***	-0.0230
	(0.2821)	(0.3123)	(0.2843)	(0.3053)	(0.2961)	(0.2911)	(0.6198)	(0.3868)
govcouncil_nonmp	-0.1853	0.0022	-0.2158	-0.0523	-0.2230	-0.0571	-0.2494	-0.0580
	(0.3728)	(0.5241)	(0.3522)	(0.4805)	(0.3521)	(0.4803)	(0.3521)	(0.4801)
$vstoxx_{t-1}$	0.0167	0.0278	0.0052	0.0243	0.0050	0.0230	0.0031	0.0174
	(0.0119)	(0.0170)	(0.0087)	(0.0172)	(0.0089)	(0.0174)	(0.0088)	(0.0170)
$excessliq_{t-1}$	-0.0010***	-0.0015***	-0.0010***	-0.0014***	-0.0010***	-0.0014***	-0.0011***	-0.0013***
	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0004)	(0.0004)
oneyearltro			9.2897***	28.1847***	9.2844***	28.1937***	9.2363***	28.2623***
			(0.1464)	(0.2506)	(0.1470)	(0.2522)	(0.1480)	(0.2408)
3yearltros			6.5485	5.7247	6.5583	5.7224	6.5433	5.6743
			(4.1343)	(8.0862)	(4.1266)	(8.0908)	(4.1624)	(8.1399)
zerorate			4.8569***	4.4933***	4.8472***	4.4835***	4.8854***	4.4398***
			(0.1530)	(0.1503)	(0.1541)	(0.1509)	(0.1679)	(0.1530)
fullallot			16.9428*		16.9426*			
			(9.6924)		(9.6915)			
No. Obs	2,158	1,558	2,158	1,558	2,140	1,546	2,089	1,481
R-Squared	0.0390	0.1801	0.0572	0.1950	0.0571	0.1943	0.0658	0.1982

Table 1.11: The collateral spread of different baskets in different time periods

The table shows the descriptive statistics of the collateral spread of GC Pooling ECB and ECB Extended baskets in eight different time periods. The collateral spread (in basis points) is measured as the difference between the Eonia and the GC repo rate. The GC repo rate is ON. Each observation of the collateral spread is the volume-weighted average for each day. The last two columns of this table show the negative occurrence of the collateral spread. The ninth column counts the number of negative days observed. The last column displays the percentage of negative days of the total number of days, when trades occur in that basket.

Jan 02, 2007 - Jul 31, 2007 (147 trading days)	No. Obs.	Mean	St. Error	Median	St. Deviation	Min	Max	# neg. days	% of neg. days of obs.
Eonia – GCP ECB rate	147	-0.48	0.41	0.03	4.95	-41.54	13.09	62	42.18%
Aug 01, 2007-Oct 08, 2008 (303 trading days)									
Eonia – GCP ECB rate	303	-3.09	0.38	-2.16	6.58	-51.11	15.88	237	78.22%
Oct 09, 2008–Jun 24, 2009 (179 trading days)									
Eonia – GCP ECB rate	178	11.70	0.66	11.28	8.86	-30.05	33.28	13	7.30%
Eonia – GCP ECB Ext. rate	101	-2.82	0.94	-1.70	9.41	-25.00	16.10	58	57.43%
Jun 25, 2009–Jul 01, 2010 (262 trading days)									
Eonia – GCP ECB rate	262	5.32	0.26	5.96	4.28	-21.48	17.53	18	6.87%
Eonia – GCP ECB Ext. rate	227	2.90	0.30	3.70	4.56	-21.50	15.10	35	15.42%
Jul 02, 2010–Dec 21, 2011 (382 trading days)									
Eonia – GCP ECB rate	382	3.50	0.35	4.76	6.93	-38.46	26.99	85	22.25%
Eonia – GCP ECB Ext. rate	381	-2.28	0.41	-0.02	8.05	-45.88	13.99	191	50.13%
Dec 22, 2011–Jun 30, 2013 (387 trading days)									
Eonia – GCP ECB rate	387	7.14	0.17	7.47	3.39	-19.82	17.86	2	0.52%
Eonia – GCP ECB Ext. rate	387	5.60	0.21	6.39	4.08	-30.17	17.62	15	3.88%
Jul 01, 2013–Jan 21, 2015 (397 trading days)									
Eonia – GCP ECB rate	397	2.49	0.17	2.58	3.47	-29.94	13.74	56	14.11%
Eonia – GCP ECB Ext. rate	397	0.09	0.25	0.72	4.89	-68.92	11.04	144	36.27%
Jan 22, 2015–Jun 30, 2015 (111 trading days)									
Eonia – GCP ECB rate	111	7.32	0.26	7.43	2.69	0.91	12.89	0	0.00%
Eonia – GCP ECB Ext. rate	111	5.13	0.36	5.43	3.83	-9.72	12.27	11	9.91%

2 The German Special Repo market: Activity and Prices

2.1 Introduction

Financial stability depends on the setup of the financial system. One important backbone of the bond market is the special repo market. In a special repo transaction a security is bought by a bank with the promise to return it at a fixed price after e.g. one week. This type of transaction helps market-makers, who often enter short positions in the bond market, to meet their clients' demand. They can borrow the security in the special repo market for delivering it to their clients, in case they currently do not own it. Despite the possibility of borrowing, a short position entails the risk of not being able to fulfill the delivery commitment. Thus, it can be expected that market-makers choose, which short positions they will enter, ceteris paribus. The underlying characteristics of the security will impact this choice (Duffie, 1996). Securities that are easy to locate in the market are likely to go more often on special, i.e. trade in the special repo market. Moreover, the close link between the bond and special repo market implies that changes in demand for bonds is reflected in the special repo market (Jordan and Jordan, 1997). When the demand of a security vastly exceeds the supply, a short squeeze can occur (Nyborg and Strebulaev, 2004; Sundaresan, 1994) which results in that security being highly special. The demand for securities is impacted by the market environment, such as volatility or monetary policies by the Eurosystem spearheaded by the European Central Bank (ECB).[1] Therefore, the questions of interest are: Which characteristics of bonds influence their special repo trading activity? How does trading in the special repo market react to external factors? And what are the potential implications for its role in the financial system?

The market environment for bonds is shaped by financial market uncertainty as well as the Eurosystem policy measures. These measures include asset purchase programmes that directly aim at the bond market and measures targeted at the interbank market

[1]In general, decisions are made and announced by the ECB, whereas the Eurosystem is responsible for the implementation of those policy decisions.

for funding liquidity.[2] Measures directed at the bond market spill over to the special repo market due to their close link. Policies aiming at the funding market have an effect on special repo through the use of collateral at the Eurosystem. The value of eligible securities is increasing in the potential use, i.e. if they can be used to obtain 1-year or 3-year central bank liquidity, their value rises.

Another Eurosystem policy measure is the switch to a negative rate on its deposit facility on June 11, 2014.[3] Given that all special repo rates are as of now negative, cash providers receive less cash at the end of the transaction than compared to their initially provided loan. This is a tangible cost for a bank's balance sheet, making reverse special repo transactions less attractive.[4] If a bank short-sells a security, it may prefer to wait until it obtains that security in the cash market rather than borrowing it in the special repo market. The bank may thus initiate a settlement's fail in the cash market. The convention in the cash market is that the delivery obligation is rolled over and the price agreed upon remains the same. Fleming and Garbade (2004) state that in the case of negative interest rates, failing on the bond delivery obligation is preferable. However, they also demonstrate that ancillary costs can force market participants to comply and borrow that security in the special repo market. Still, it can be overall expected that the number of special repo trades declines after the switch to a negative policy rate.[5] Therefore, Eurosystem policies have wider effects on financial markets than intended. The analysis of the reaction of the special repo market to those policies will help to gain a better understanding of this market and to evaluate wider-ranging consequences of Eurosystem policies.

In this paper I study special repo transactions from two angles. First, I examine security-specific characteristics using cross-sectional data. This allows me to identify, which characteristics of a bond drive its trading in special repo. Second, I examine those external factors in a fixed-effects regression, to disentangle the results from security-specific effects and to focus on the impact of the market environment on the whole special repo market. The data on repo transactions was received from Eurex Repo, a German company providing a platform for electronic repo transactions. The securities traded on

[2]Nyborg (2017a) also discusses the impact of the change in the collateral framework designed by the ECB on financial markets. The focus in this paper is on Eurosystem market actions.

[3]Holding cash now becomes expensive. Banks are forced to look for investments with non-zero returns.

[4]ICMA (2015) reports that cash providers in GC repo are dissatisfied with negative repo rates.

[5]A different factor that plays a role is the start of the implementation of Basel III, which shifts incentives to trade in the repo market in Europe. The Basel III rules, adopted in Europe in the CRD IV package have to be applied gradually from January 01, 2014 and to be fully implemented by January 01, 2019 (http://www.eba.europa.eu/regulation-and-policy/implementing-basel-iii-europe, ICMA (2015)). Shortly speaking, trading in repo, especially short-term, becomes more expensive in terms of capital. This might also reduce the use of repo in market-making activities.

that platform are predominantly German bonds, e.g. covered or corporate bonds, even though trades in e.g. Spanish government bonds are possible. Given that Eurex Repo allows a smaller set of securities as collateral than the Eurosystem, those securities are usually eligible to use as collateral for central bank liquidity. The sample period ranges from January 01, 2007 to June 30, 2015. The data contains the repo rate, the ISIN, transaction date, purchase date, repurchase date, volume, type of transaction, and type of security. My interest centers around the special repo transactions.[6] This market has an outstanding volume of EUR 53 billion as compared to the overall volume in the European repo market, EUR 5,600 billion (European Repo Council survey, December 2015), measured on June 10, 2015. On average, there are 235 transactions per day. My focus is on transactions with a term of one-week, which constitute the majority of trades in special repo (71.3%). This data is complemented by bond data from Datastream, data on the VSTOXX from Bloomberg, and data on Eurosystem policy measures.

The empirical analysis starts with cross-sectional regressions at the bond level. There are four dependent variables: i) the number of trades, ii) volume iii) the special repo spread[7] and iv) specialness, which is measured as the difference between the general collateral (GC) rate and the special repo rate. The lower the special repo spread and the larger specialness is, the more expensive is the bond in special repo. All four variables are regressed on the issue size, age of the bond, the term of the bond, and the type of the bond. The major explanatory variable is the issue size of the bond. The larger the outstanding amount is, the more often the bond trades special, and the lower its specialness tends to be. Jordan and Jordan (1997) and Corradin and Maddaloni (2015) both measure the supply of the bond by its availability, as e.g. a fixed amount might be held by buy-and-hold investors. Still, according to my results a larger issue size implies a larger supply of this bond. This makes it easier to locate when needed and market makers/dealers are more willing to trade in this bond. This result is also in line with Duffie (1996), who states that out of two similar securities the one with lower frictional trading costs will trade special. According to Friewald, Jankowitsch, and Subrahmanyam (2012) a larger issue size implies that this bond is more liquid.

The next step is to examine the impact of market factors on the special repo market. I run fixed-effects panel regressions at bond level, in which I include the VSTOXX for measuring financial market uncertainty and different variables capturing Eurosystem policy measures as independent variables. The Eurosystem variables contain excess liquidity, announcement days of asset purchase programmes, changes in the outstanding

[6]The GC repo transactions are eliminated in this analysis, but kept for calculating specialness.

[7]The effective policy rate is subtracted from the special repo rate, as the level of special repo rates depend on the overall interest level. Before October 09, 2008, this is the minimum bid rate (MBR) and afterwards the rate on the deposit facility (also see Nyborg (2016)).

purchase volumes of the asset purchase programmes, the rate on the deposit facility, dummy variables capturing the periods before the first one-year Long-term refinancing operation (LTRO), before the start of both three-year LTROs, quarter- and year-end, and the respective day of the week. In addition, there is one dummy that obtains the value of one, when the ECB changes the policy rate from zero to negative on June 11, 2014.

The results of the panel regressions shed light on the impact of financial market uncertainty, and Eurosystem unconventional monetary policy, i.e. creation of excess liquidity and asset purchase programmes. Financial market uncertainty lowers volumes in the special repo market and specialness rises. This indicates risk adjustment by rationing and higher premia for repo trades, which is in line with a flight-to-liquidity. Duffie (1996) shows that liquid securities go more often on special. According to Vayanos (2004) and Beber, Brandt, and Kavajecz (2009), there is a quest for liquidity in volatile times, which shows up here in higher specialness. Excess liquidity by the Eurosystem has a similar effect on the special repo market: it decreases activity and special repo spreads fall. The reason is that the value of eligible securities (which applies to securities trading on Eurex Repo) rises, when the Eurosystem offers long-term financing.

Moreover, the covered bond purchase programmes also dampen trading in special repo. They tend to lower the number of trades and daily traded volumes, whereas contrary to expectations specialness of covered bonds decreases on average. This might stem from the fact that the covered bond market is more liquid again, in which case the GC rate drops relatively more than the special repo rate. In addition, some bonds may be very scarce due to the Eurosystem purchase programmes, whereas the demand for other non-bought bonds falls. The same holds for the Public Sector Purchase Programme.[8] Overall, the current demand for government bonds is high, and the demand for other bonds falls. Finally, the switch to a negative policy rate also has a an adverse impact on the market. It is followed by lower activity in the special repo market.

The effect of the negative policy rate is examined in more detail in Section 2.4.3, where I restrict the sample to bonds that mature after September 11, 2014, three months after the policy change. Further, I require that the bonds must trade before and after the change of the policy rate to enable a pre-post-analysis. I run the same fixed effects panel regression as before, but with different windows around the event. The shortest window is one month. The switch to a negative rate lowers the number of trades and the daily traded volume in each bond. This effect strengthens over time.[9] The special repo spread decreases slightly, by one basis point. The cost of lower cash at the term leg of the

[8]The Quantitative Easing by the Eurosystem was announced on September 04, 2014, and includes the covered bond purchase programme 3 (CBPP3) and the asset-backed purchase programme. On January 22, 2015, the public sector purchase programme was added.

[9]This trend is probably supported by the start of Basel III.

transaction leads market participants, in all likelihood, to avoid trades in the special repo market. It is shown that after the switch more expensive securities trade less often than cheaper ones. At the same time, the daily volume shrinks for less expensive securities. Interestingly, the average specialness of more expensive securities falls more than the specialness of cheaper securities after the change to a negative policy rate. These results support the notion that the negative policy rate reduces the appeal for special repo in market-making activities, which might be strengthened by current changes in regulation.

To summarize, the special repo market reacts strongly towards external factors: financial market uncertainty, Eurosystem liquidity policies, and asset purchase programmes. Transactions in the special repo market decrease, potentially impacting market liquidity in the bond market. The same is true for the negative policy rate. A lower willingness to transact in the special repo market might lead to a deterioration of bond market liquidity. Lower bond market liquidity may in turn facilitate the potential for short squeezes in the special repo market. Moreover, bond prices are an important input for the risk management by banks and the ECB. If less information on prices is available, risk management becomes more difficult, potentially leading to lower financial stability. In general, if one market in the financial system is affected by a policy measure, there are usually spillovers to other markets. Creating a better knowledge of these interdependencies helps to evaluate policy measures and impacts on the financial system overall.

The literature and research on special repo is scarce so far. Duffie (1996) provides the foundation for research on special repo. He shows that a bond that trades on special earns a higher price in the cash market. Trading special is an endogenous phenomenon. If two securities are similar, the security with the lower trading cost is likely to go on special. Securities that are easier to trade will thus be more often on special than other securities. Jordan and Jordan (1997) investigate several of Duffie's predictions and confirm the relationship between a bond's specialness and its price. In addition, they find that auction tightness and the percentage awarded to dealers impacts subsequent specialness. Buraschi and Menini (2001) add to the understanding of specialness, by applying the expectation hypothesis to special repo rates. Their results yield that special repo rates contain a time-varying liquidity risk premium. Fisher (2002), Krishnamurthy (2002), Moulton (2004), and Graveline and McBrady (2011) study specialness in the context of the on-the-run phenomenon in the United States. They find that on-the-run securities have a premium in the bond market over the previous on-the-run security, but trading profits are zero due to the difference in repo-market financing rates. Fleming and Garbade (2007) compare the Fed's securities loan programme from 1999 to 2002 with the specials market and find no violation of the law of one price. A more recent paper by Corradin and Maddaloni (2015) analyze the specialness of Italian government bonds. They document that a large buyer in the market of bonds has a huge impact on the special repo market. Their focus is on the SMP by the ECB that aimed at buying bonds from Eurozone countries with high credit risk. This analysis is complemented by Dufour, Marra, Sangiorgi, and Skinner (2017), who find for Italian sovereign bonds that specialness increases in the bid-ask spread and they identify patterns around auction dates. So far the emphasis of the special repo literature has been on specialness. This paper adds to the literature by studying the number of trades and volumes in the special repo market in addition to special repo rates and specialness.

The complement to the special repo market is GC repo, where the primary motive for trading is cash funding. Cash is lent against a basket of securities, and not against a specific security. Mancini, Ranaldo, and Wrampelmeyer (2016) show the determinants of GC repo rates on the Eurex Repo platform. A detailed description of this market can be found in Ebner, Fecht, and Schulz (2016). My paper provides the counterpart to Mancini, Ranaldo, and Wrampelmeyer (2016) with the focus on special repo transactions. In line with their result that excess liquidity reduces activity in GC repo, I show that excess liquidity also lowers activity in special repo. My paper broadens the understanding of the repo market in Europe and Germany. There are also several studies on the repo market in the United States. Gorton and Metrick (2011) document the run on bilateral repo transactions during the financial crisis. Krishnamurthy, Nagel, and Orlov (2014) argue that triparty repo in the US did not experience a run. Bartolini, Hilton, Sundaresan, and Tonetti (2011) are the first to denote that there are differences in GC repo rates that relate to the credit and liquidity risk of the underlying security.

The effects of central bank policy are more and more put into spotlight. In this paper I study among other factors the impact of Eurosystem policy measures on the special repo market. Dunne, Fleming, and Zholos (2013) show that there is a substitution between Eurosystem and interbank repo market liquidity. Krishnamurthy, Nagel, and Vissing-Jorgensen (2017) find that the Eurosystem unconventional monetary policies, in particular the SMP, Outright Monetary Transactions, and LTROs, significantly lowered sovereign bond yields. Their result is confirmed by Szczerbowicz (2015), who observes that the covered bond and sovereign purchase programmes decrease both bank covered bond spreads and sovereign bond spreads. The effects of liquidity allocation in the ECB's open market operations are studied by Bindseil, Nyborg, and Strebulaev (2009) and Fecht, Nyborg, and Rocholl (2011). They analyze if the allocations at the ECB liquidity auctions are linked to banks' liquidity positions and find that banks bid more aggressively the more imbalanced the last auction results were. Banks are also willing to pay more for liquidity if banks' liquidity reserves at the Central Bank are more dispersed.

The paper proceeds as follows. In Section 2.2 the special repo market and the electronic trading system of Eurex Repo are described. This is followed by an explanation of the data used and descriptive statistics in Section 2.3. Section 2.4 contains the empirical analysis and Section 2.5 concludes.

2.2 The special repo market and Eurex Repo

There are two legs in a repo transaction. A security is sold to the cash giver at the purchase date and re-bought by the cash taker at the repurchase date. That security is usually a bond and it serves as collateral in the transaction, since repo is often understood as a collateralized transaction. If the cash taker defaults, the cash giver can sell the security in the market.[10] The negotiable items are the repo rate, the volume, and the term.[11] At the end of the contract, the cash giver receives the initial cash amount plus the repo rate. There are two types of repo transactions, general collateral (GC) and special. In a GC repo transaction, the driver of the transaction is cash funding. The result is that the cash taker can deliver securities from a basket, which are of the same type and quality. In special repo, the transaction is initiated by the cash giver, who needs a specific security. The special repo rate is usually below the GC rate, which is the interest rate for liquidity. The price of the security is the difference between the GC rate and the special repo rate, called specialness. It measures the foregone opportunity cost of the cash giver, i.e. the security taker, to lend his cash at the GC market rate.

The special repo market is crucial for market-making activities in the bond market. If a market-maker sells a bond to an investor, he might not have this bond in his portfolio.[12] In order to fulfill his commitment, he can borrow this bond in the special repo market. This gives him time to locate the bond in the cash market. On Eurex Repo 71% of all transactions take place in the one-week segment, which fits to the characterization of market-makers needing time. Securities might be easier/faster to find in the special repo market than in the bond market due to the fact that buy-and-hold investors such as insurance companies are willing to lend their bond, but not sell it. The advantage for them is that they can earn an additional revenue on their securities. They can invest the cash they receive from the security taker at the market interest rate, e.g. GC repo rate, and pay the lower special repo rate to the security taker. So they earn the specialness premium on the security they have lent.

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[10]The difference between the price in the repo transaction and the market price is then usually settled between these two counterparties according to the contract GMRA.

[11]In bilateral repo transactions, the haircut is also part of this set, but not on Eurex Repo, where the haircut is calculated by the CCP.

[12]This type of shortselling must be distinguished from the shortselling that is used to bet on a fall in prices.

Eurex Repo, a German company, provides a platform for electronic repo trading.[13] It offers GC repo and special repo trades in different types of securities for credit institutions and investment banks. The participants on this platform can for instance trade German government bonds or German Pfandbrief securities. Many security types are German, but there are also French covered bonds or European government bonds. Trades are anonymous and cleared by the Central Counterparty (CCP) Eurex Clearing. Trades are marked as 'special' by traders, who indicate in their quote, if they are looking for a specific security. Different standard contract terms are offered by Eurex Repo. They range from overnight to twelve months. In addition, counterparties can also agree on a flexible term. The securities traded are of high quality. The lowest rating allowed in special repo is A-. The security in a special repo transaction is transferred to the cash giver's account. Most securities that trade special on Eurex Repo are eligible as collateral at the Eurosystem. Thus, any policy measure that aims at the bond market or changes the demand for collateral affects special repo. This is discussed further in Section 2.4.1.

2.3 Data and Descriptive Statistics

The special repo data consists of 510,173 transactions on the Eurex Repo trading platform. 363,940 transactions have a term of one week, which constitute the sample. The data contains transaction day and time, type of the security, ISIN, rate, volume, purchase day and repurchase day. About 50%, i.e. 174,964, of all transactions occur in a German ISIN number. The analysis covers the period from January 01, 2007 to June 30, 2015. The securities traded are classified into 25 different types. Some types overlap because Eurex Repo has changed the definition of the types over time. In addition, a bond can fall into two different classifications, which I account for in the analysis. The dataset contains a range of different bonds, such as government bonds, or European covered bonds. Some bonds are not assigned to a bond class, but may just be marked as trading special.

The first dependent variable I examine is frequency: how often does a bond trade special? It is defined as the number of transactions per trading day, *freq*. The second variable of interest is traded volume. In the cross-sectional regression it is defined as volume per transaction, and in the fixed effects regression as traded volume in one bond per day. I analyze the log of this variable, as it is highly skewed to the right, *logvolume*. The third variable is the difference between the special repo rate and the key policy rate. On October 09, 2008 the ECB changes from a liquidity-neutral monetary policy framework

[13]Eurex Repo is a subsidiary of Eurex Frankfurt AG, which belongs to Deutsche Börse Group.

to full allotment, i.e. all banks now receive unlimited credit against collateral.[14] Given the large amount of liquidity, interest rates fall towards the deposit rate. Instead of the minimum bid rate, the effective policy rate becomes the deposit facility rate (Nyborg, 2016). Until October 08, 2008, I subtract the minimum bid rate, and from then on the deposit facility rate, *diffrate*. The lower the spread is, the more expensive that security is in special repo. The spread of the special repo rate is complemented by the specialness of a bond, *specialness*.

In order to measure specialness, I calculate the difference of the daily volume-weighted average GC rate to the special repo rate. The GC rate is computed from GC transactions on Eurex Repo. The matching involves three steps. First, the GC rate is matched for the same type of security, purchase day and the term of one week. Second, covered bonds are one type of security, without the distinction between German Pfandbrief and French Covered bond. If there is no match for a covered bond for the exact same type of security, the volume-weighted average GC rate for all covered bonds trading on that day is used. Third, the best estimate for the specialness of the other securities without a match is the difference between the volume-weighted GC rate of all transactions for the same purchase day and term of one week. This pooled GC rate is used in the third step. The total match is 167,880 transactions (46% of all one-week transactions). There are still transactions without a corresponding match, because the electronic GC repo market is mainly overnight, and less frequently long-term. Specialness is restricted to be positive.[15] The larger the specialness of a specific security is, the more expensive this security is.

[**insert Tables 2.1 and 2.2 about here**]

Table 2.1 presents descriptive statistics for all dependent variables, bond characteristics and market environment variables. Data on bond characteristics was downloaded from Datastream. The data for the VSTOXX stems from Bloomberg. Variables describing Eurosystem policy measures are taken from the ECB webpage. The sample is composed of 3,223 bonds and spans a period of 2,171 days. On average, each bond is traded 158 times and has a total traded volume of EUR 2,750 million. Their special repo rate is about 60 basis points (bps) and their specialness 20 bps. About 157 bonds trade special every day. The average contract term is 7.6 days. The lower part of Table 2.1 displays the total trading volume in each type of security. Euro Covered Bonds are the largest group with 571 bonds. The largest average trading volume of a bond belongs to the group

[14]Nyborg, Bindseil, and Strebulaev (2002) define liquidity neutral monetary policy as an allotment policy that allows banks to satisfy their reserve requirements on average during the maintenance period.

[15]The opportunity cost in the special repo transaction is the GC rate, so the security taker will at least offer this rate. There might be deviations in the best estimate of the corresponding GC rate, even among repo traders. Since negative observations might be due to different estimates, I eliminate those.

of German government bonds with EUR 34 billion. This is linked to the issue size, as German government bonds are usually large: their average issue size exceeds EUR 10 billion. The second largest trading volume per bond can be identified for KFW bonds with EUR 6.7 billion, whereas the lowest trading volume belongs to European corporate bonds (EUR 167 million).

Further statistics by type of security can be found in Table 2.2, which displays average figures for the number of trades, specialness, and further key features of the sample. The highest average frequency can be found for KFW bonds with 471.4 trades by bond. The largest specialness belongs to Finnish government bonds, which rarely trade special. Furthermore, there are wide differences between types of bonds: the lowest average trade pertains to Belgian and French government bonds with 3.50 trades and 4.12 trades (besides Spanish sovereign bond with one trade). French government bonds have the lowest average specialness of 0.10%, but the largest average issue size of EUR 18.3 billion. The second largest issue size belongs to German government bonds (Germany) with EUR 17.1 billion, which are traded on average 343.8 times and have a low specialness of 0.15%. Frequency and specialness are related to the type of bond and further characteristics. Since my interest centers around characteristics, I will control for bond type effects. With respect to the term, the average lies between seven and eight days, with the longest being 50 days (Spanish government bond). This reflects the fact that the term of one week is the most important one in special repo on Eurex Repo.

2.4 Analysis

The analysis focuses on one-week contracts in the special repo market, the most actively traded contracts. I identify three blocks of drivers for the special repo market: a) bond characteristics, b) financial market uncertainty, and c) Eurosystem monetary policy operations. In the last part of the analysis I focus on the ECB's switch to a negative policy rate and its impact on the special repo market. The negative policy rate is implemented to stimulate the circulation of cash and investments. If there is an impact on the special repo market, this move to negative rates has potentially unintended side effects. Such side effects need to be understood to evaluate the effectiveness of such a policy decision. Next, I discuss all potential drivers.

2.4.1 What are the drivers of the special repo market?

In the special repo market the characteristics of a bond are crucial for its trading frequency and specialness (Duffie, 1996). The demand for a specific security determines how often a security trades special and how special it is. If there is high uncertainty in financial markets, investors will be more risk-averse to trade. Over time, the Eurosystem policy operations have an impact on special repo. Its liquidity injection, asset purchase programmes, and the impact of its policy rates will steer activity in special repo. The effects of those drivers are explained and investigated in detail in the following paragraphs.

Bond characteristics

Duffie (1996) shows that out of two similar securities, the one with lower frictional trading costs is more likely to go on special. The issue size of a bond facilitates trading in this bond. The bond supply is larger and this increases the likelihood to trade on special. Thus, I include the log of the issue size in the regression, *logissuesize*. As reported in Table 2.1 the average issue size is EUR 3 billion with a maximum of 43 billion. Jordan and Jordan (1997) show that specialness is decreasing in the availability of a bond. The older the bond is, a larger volume of it tends to be held by buy-and-hold investors. The supply of this security decreases. Further, it is traded less in special repo and with lower volumes. When it trades, it tends to have a lower rate and a higher specialness. This is captured by the age of the bond, when it trades, *age*. The average term of a bond is seven years, with the maximum being 51 years. In addition, I account for the term of the bond, *term*, i.e. the maturity of the bond at issue date. Longer-dated bonds are also believed to be bought by buy-and-hold investors, who trade less frequently. In fact, these three factors are identified by Friewald, Jankowitsch, and Subrahmanyam (2012) as liquidity proxies of a bond based on its characteristics.

Financial market uncertainty

Nyborg and Östberg (2014) show that banks adjust their portfolios, when financial market uncertainty increases. Uncertainty has an impact on stocks and bonds by changing their demand for bonds. This shift in demand will be reflected in the special repo market. In fact, in volatile times there is a flight-to-liquidity, in which the premium on liquid securities rises (Beber, Brandt, and Kavajecz, 2009; Vayanos, 2004). Securities traded in Euro Repo are on average more liquid than the whole bond market, as only a selected number of securities (e.g. excluding ABS) can be traded. Further, liquid securities go more often on special (Duffie, 1996). Thus, one can expect to observe more special repo trades. In addition, a risk premium might be added in all special repo trades, since it becomes more difficult for the security lender to predict if he will need the security himself in the next few days. Therefore, he requires a compensation for this risk. Special repo spreads decline, whereas specialness increases. The measure for financial market uncertainty is the lagged VSTOXX. It captures the expected volatility in the stock market over the next

30 days. In the sample period VSTOXX varies between 12.71 and 87.51 index points (Table 2.1).

Eurosystem monetary policy operations

The period 2008 to 2015 is marked by extensive markets interventions by the ECB. Three factors are expected to significantly impact the special repo market: a) negative policy rate b) asset purchase programmes, and c) liquidity injection.

a) Switching to a negative policy rate: on June 11, 2014 the policy rate switches from zero to negative. I capture this switch by a dummy variable that is equal to one starting on this date (*belowzero*). This change from zero to negative policy rate is important, because ultimately all special repo rates will reach very negative levels. The effect of negative rates is that the cash taker/ security lender in the repo transaction returns a lower cash amount than he had originally received, i.e. the cash giver/ security taker pays extra for receiving the security. This is problematic for banks if they enter a repo transaction and they obtain a lower cash amount at the term leg than before. The cash amount on the balance sheet is effectively reduced by entering a repo transaction. If a bank needs to fulfill a short selling obligation, it may choose to fail it rather than borrowing the security in the repo market at a negative interest rate. The obligation in the cash market is rolled over to the next day at no cost, if there are no settlement fail penalties in place.[16] The opportunity cost for cash is the GC overnight rate. Fontaine, Hately, and Walton (2017) argue that in the case of negative rates, the lower floor of the special repo rate is the GC overnight rate. Thus, it might be better to invest the cash at the GC overnight rate and wait for the opportunity to buy the security instead of using the special repo market for delivery. Reputational costs will restrain this behavior (Fleming and Garbade, 2004), but it can generally be expected that special repo trades will decline and specialness premia decrease on average, which I will test in Section 2.4.3.

b) Asset purchase programmes: they affect the demand for securities. Corradin and Maddaloni (2015) find that an increase in holdings of Italian government bonds within the Securities Markets Programme (SMP) is linked to higher specialness.[17] The four programmes that affect the Eurex Repo special repo market are the covered bond purchase programmes (CBPP) 1-3 and the public sector purchase programme (PSPP), which is part of quantitative easing (QE). The CBPP involves the purchase of covered bonds and the PSPP European government bonds. The ECB publishes the outstanding volumes

[16] In Germany (Clearstream), the settlement instruction is just rolled over to the next day, as long as the security matures or the instruction is deleted by both counterparties.

[17] In this data set the SMP is not expected to have an effect as it was targeted at GIIPS government bonds. Those are not part of the dataset or do not show many transactions as the Spanish government bonds.

of the Eurosystem programmes on a weekly basis. I calculate the weekly change in those volumes for the period that the programmes are active (*changecbpp1, changecbpp2, changecbpp3, changepspp*). Since CBPP focuses on the covered bond market, only the effect on covered bonds is measured. I also exclude bonds from these variables, whose issue size is below the eligible size announced by the ECB. The minimum issue size of CBPP1 is EUR 500 billion, and it is EUR 300 billion for CBPP2. There is no such restriction for CBPP3. The CBPPs are focused on the covered bond market. The PSPP has a larger reach, since it is much bigger in size: it has a maximum change of EUR 16 billion, whereas the largest covered bond programme is CBPP3 with a maximum change of EUR 5 billion (Table 2.1). The larger the change in purchases is, the higher is the pressure on special repo rates and specialness increases. Volumes should not be affected. In addition, I include dummies for the announcement days of those programmes (*cbpp1announce, cbpp2announce, cbpp3announce, qeannouncement*). CBPP1 is announced on May 07, 2009, CBPP2 on October 06, 2011, CBPP3 on September 04, 2014, and PSPP on January 22, 2015.

c) Liquidity injection: the Eurosystem injects liquidity against eligible collateral. Banks can use their eligible securities for obtaining liquidity from the Eurosystem. This option is very attractive in the Eurosystem long-term refinancing operations (LTRO) of more than one year. Those operations usually instigate a large demand for liquidity.[18] The potential of obtaining long-term financing from the central bank raises the value of eligible securities, to which securities traded on Eurex Repo belong. Thus, special repo rates fall relative to the effective policy rate. The abundance of liquidity may lead banks to recede from the interbank market, thus lowering activity. This effect is captured in the variable of *excessliq*, which is defined as the sum of volumes at the current accounts and deposit facility minus volumes at the lending facility and reserve requirements. Its average during the sample period is EUR 193 billion (Table 2.1) with a minimum of -EUR 134 billion and a maximum of EUR 812 billion. In addition, I include dummy variables that are equal to one the period before a LTRO with a long maturity *before1year, beforeltro1, beforeltro2*. *before1year* measures the effect for the period between the announcement (May 07, 2009) before the one-year LTRO in June 24, 2009. *beforeltro1* and *beforeltro2* capture the effect of the time span between the announcement on December 08, 2011 and the implementation of both 3-year LTROs, December 21, 2011, and February 29, 2012.[19] The idea is that the demand for collateral is very high before the start of these LTROs. This will be reflected in the special repo market. I expect the number of transactions,

[18] In the first one-year LTRO banks demand EUR 442 billion, and in the two three-year LTROs, the total liquidity injected amounts to nearly EUR 1 trillion.

[19] The Eurosystem liquidity policies are discussed in more detail in Nyborg (2017b).

traded volume and specialness to be higher, and special repo spreads to be lower. In the regressions I will also control for the period of full allotment (*fullallot*) starting on October 09, 2008. Banks now receive all credit they demand from the Central Bank, which is a response to severe disruptions in the interbank after the collapse of Lehman Brothers on September 15, 2008. This fundamental change in monetary policy might affect the dependent variables.

2.4.2 Regression analysis

In my analysis I separate the security-specific factors from external factors that influence the activity in the special repo market. In the first part I conduct a cross-sectional regression testing for the impact of bond characteristics. In the second part I run a fixed-effects panel regression testing for the effect of market factors. In the third part my interest centers around the impact of a recent policy measure by the ECB, the switch to a negative policy rate.

Cross-sectional regressions

In this section I test for the impact of bond characteristics on their frequency per trading day (*freq*), the volume per transaction (*logvolume*), the difference between the special repo rate to the policy rate (*diffrate*) and specialness (*specialness*). To be more precise, I take the total number of trades over the sample period, the average of volume in each trade, the volume-weighted average spread, special repo rate – policy rate, and volume-weighted average specialness for each bond. Then I regress each dependent variable on the log of the issue size of each bond (*logissuesize*), its average age (*age*), its term (*term*) and on dummies for each type of security ($\sum_1^{25} \alpha_k$). Age is calculated as the average of the period issue day – transaction days, and is measured in years. The term, also measured in years, is equal to the time span issue date - redemption date. A security can belong to more than one type. If a security is classified as German Pfandbrief and European covered bond, then the dummy for each equals one. Several types can only be traded later in the sample period, i.e. a security might appear to trade less than another security, but in fact the basket can only be traded starting 2012. The dummies subsume this effect. Since the sample period contains time-varying effects, which might affect the dependent variables, the regression is also conducted solely for the year 2007, excluding all extraordinary policy measures. Thus, I run the following regression:

$$y_i = \alpha_1 + \alpha_2 logissuesize_i + \alpha_3 age_i + \alpha_4 term_i + \sum_5^{29} \alpha_k Type_i + \varepsilon_i. \tag{2.1}$$

Table 2.3 presents the results. Each regression contains 25 dummy variables for the type of security, whose coefficients are not reported. The main explanatory variable is the issue size of each bond. If the issue size is higher by 10%, the bond trades on average 0.0061 times more often each day. The volume in each transaction is higher. A 10% increase translates into a 3.8% increase in volume. The special repo spread tends to be higher by 0.49 basis points. This translates into a lower specialness of about 0.58 basis points. In the whole sample period as well as for the year 2007 the term of the bond is statistically significant at the 5% level for the frequency of trading with coefficients of 0.0038 and 0.0026 respectively. There seems to be a preference to trade in long-term bonds, despite the notion that mainly buy-and-hold investors invest in those bonds. This variable is also significant for the other dependent variables in the whole sample period, but not if only the year 2007 is considered. The effect of term on the frequency of trading is counteracted by age. An increase by one year lowers the number of trades per trading day by -0.0069, which is significant at the 1% level for the whole sample period. Older bonds tend to trade less often on special, which is in line with a larger share of the bond being owned by buy-and-hold investors.

[**insert Table 2.3 about here**]

The main result from the bond characteristics is that issue size is an important determinant of how often the bond trades special and for its rate. This is in line with Duffie (1996), who predicts that a bond with lower frictional trading cost will trade more often on special. The larger the issue size is, the larger is the supply of the bond in the market, given its type. Thus, its special repo spread tends to be higher and its specialness lower. The size of a bond issue or of one issuer, such as a country, leads to self-coordination, as shown by He, Krishnamurthy, and Milbradt (2016) in their theoretical model. As investors know that other investors trade more often in this bond, they will also trade in this bond, given its type. So it is no wonder that the issue size of a bond impacts the demand and special repo trades for this bond. The next section focuses on the impact of external factors on the special repo trades of a bond.

Panel regressions

Trading in special repo is a function of a bond's characteristics, but also external factors. These external factors are ECB monetary policy decisions, including its asset purchase programmes, the introduction of negative interest rates, and the amount of liquidity distributed (Section 2.4.1). I run a fixed effects panel regression at the bond level. The time variable is the transaction day. Standard errors are clustered at the bond level. The dependent variables are the frequency of trades in one bond per transaction day (*freq*), the log of the volume of a bond per day (*logvolume*), the volume-weighted average spread of the special repo rate to the policy rate per day (*diffrate*), and the volume-weighted average specialness per day (*specialness*). The variables *freq* and *logvolume* are demeaned.

I run the following regression to estimate the effects on the dependent variables:

$$y_{i,t} = \beta_1 + \beta_2 belowzero_{i,t} + \beta_3 excessliq_{i,t-1} + \beta_4 vstoxx_{i,t-1} + \sum_{m=5}^{7} \beta_m cbppannounce_{i,t} \\ + \sum_{m=8}^{10} \beta_m changecbpp_{i,t} + \beta_{11} psppannounce_{i,t} + \beta_{12} changepspp_{i,t} + X\beta + \varepsilon_{i,t}. \tag{2.2}$$

The variable *belowzero* is a dummy variable that is equal to one when the ECB changes the rate on the deposit facility to negative, i.e. from June 11, 2014 until the end of the sample period. *excessliq* measures the excess liquidity (in the Euro area), lagged by one day, and measured in billion. *vstoxx* is the VSTOXX, also lagged by one day. *cbppannounce* are three dummy variables that are equal to one on the days that the CBPP 1-3 are announced. *changecbpp* are three variables that measure the change in outstanding volumes for CBPP 1-3. In the regressions they are all measured in billions. *psppannounce* is a dummy variable equal to one on January 22, 2015. *changepspp* is equal to the change in outstanding volumes of the PSPP, also in billions. The control vector X contains further dummy variables: the variables *before1year*, *beforeltro1*, and *beforeltro2*, which are equal to one for the period before the large long-term LTROs.[20] *fullallot* is a dummy variable that is equal to one from October 09, 2008 to the end of the sample period. *depositfacility* captures the level of the interest rate on the deposit facility.[21] Further variables in X are controls for seasonal effects. These controls include dummies for the day-of-the week, quarter-end and year-end dummies. As shown in Chapter 3 and by Munyan (2015), banks tend to reduce their exposure to the GC repo market at the end of the quarter, mainly due to window dressing (Gropp and Heider, 2010). The same effect can be expected to be present in special repo. In addition, I use three dummy variables capturing three lags of the futures delivery day of German government bonds.[22]

[insert Table 2.4 about here]

Table 2.4 displays the results for the variables of interest.[23] The switch to a negative policy rate, financial market uncertainty, and excess liquidity all decrease activity in the

[20] *before1year* is equal to one from May 07, 2009 to June 24, 2009. *beforeltro1* is equal to one from December 08, 2011 to December 21, 2011. *beforeltro2* is equal to one from December 22, 2011 to February 28, 2012.

[21] This rate is left out in the regression of *diffrate*, because it is subtracted from the special repo rate.

[22] German bunds have to be delivered on the tenth of the end-of-quarter month or the next following business day.

[23] Seasonal effects and the rate on the deposit facility are not shown.

special repo market and increase prices (lower special repo spread, higher specialness). Financial market uncertainty, (*vstoxx*), has a strong effect on volume, the special repo spread and specialness. Specialness rises, whereas the volume and the special repo spread tend to decrease. If the VSTOXX increases by ten index points, specialness is positively affected by 3 bps, whereas volume decreases by 2.4%, and the special repo spread is lower by 12 bps. Negative policy rates (*belowzero*) decrease the frequency of trades by -0.13. This coefficient is significant at the 1% level. The special repo spread is also reduced, while specialness is not affected. The ECB excess liquidity (*excessliq*) has a significant impact at the 1% level on the frequency of trading, the special repo spread and specialness. It decreases the frequency by -0.01, if it rises by EUR 100 million. The special repo spread is lower by 5 bps, and specialness rises by one basis point. In relation to the supply of funding liquidity by the ECB, activity in the special repo market before the three-year LTROs tends to be subdued. Frequency is lower before the first three-year LTRO, and the daily volume is smaller in the period from the announcement to the start of the second three-year LTRO. However, before the first one-year, the first and second three-year LTRO, specialness is higher by 16, 8 and 12 bps, respectively. This indicates that securities have a larger price in special repo, since they can be used to obtain liquidity from the ECB for a long time period.

As can be seen, the asset purchase programmes also dampen activity in the special repo market, but specialness rather goes down than up. First I discuss the impact of the announcements, before I move to the volumes. The announcements of CBPP1 and CBPP2 influence the special repo spread and specialness. The announcement of CBPP1 (*cbpp1announce*) goes along with lower special repo spreads (-6.4 bps) and lower specialness (-9.6 bps). The announcement of CBPP2 leads to higher special repo spreads (9.8 bps) and also lower specialness (8.7 bps). The announcement of CBPP3 has no obvious effect. The implementation of CBPP1 lowers the number of trades (*freq*). The coefficient of -0.11 is significant at the 5% level. The coefficients are also negative for CBPP2 and CBPP3, but not significant. Instead of the frequency, CBPP2 affects *logvolume*. If there is a positive change of EUR 100 million in CBPP2, then the volume tends to be lower by 5.3%. The implementation of CBPP1, *changecbpp1* decreases special repo spreads and specialness on average in the special repo market. A EUR 1 billion change is followed by a decrease of 18 bps in specialness. Special repo spreads also decrease by 17 bps. A change in the volumes of CBPP2 only affects the special repo spread, but not specialness. A larger purchase volume by EUR 100 million would lead to a decline in special repo spreads by 0.9 bps. CBPP3 only affects the special repo spread. Contrary to CBPP1 and CBPP2, the coefficient on *diffrate* is positive and significant for a change in volumes of CBPP3. Special repo spreads increase by 1 basis point, if CBPP3 changes by EUR 100 million. It can be noted, when comparing all covered bond purchase programmes, that CBPP1 has the largest influence on the number of trades per day, and specialness in covered bonds.

The biggest asset purchase programme by the Eurosystem is its PSPP (part of QE), which aims at the whole financial market. Its impact is similar to the covered bond purchase programmes. The announcement on January 22, 2015, is followed by less trades in the special repo market on the same day. On average it is lower by 0.22. Specialness rises by 5 bps. The change in outstanding volumes of the PSPP (*changePSPP*) affects the frequency of trading, special repo spreads, and specialness. The frequency of trading decreases by -0.0059 if the change amounts to EUR 1 billion. The special repo spread is higher by 0.32 bps, and specialness lower by 0.28 bps. Like the other purchase programmes, PSPP also calms down the special repo market.[24] [25]

The Eurosystem policies and the market environment have a strong impact on the special repo market. The prediction that a negative policy rate lowers activity in the special repo market is backed by the data, as the frequency of trading decreases. This effect is investigated in more detail in Section 2.4.3. This is important, because - due to its close connection to the cash market - there might be spillovers from the special repo market to the cash market, such as a decrease in market liquidity. The effect of Eurosystem excess liquidity is also confirmed by the data. Special rates decrease, as the value of eligible securities rises, if banks can obtain long-term financing from the Eurosystem. Trading activity in the special repo market is also lower, as banks potentially reduce their interbank activity. Specialness rises slightly, implying that special repo rates fall more than GC rates (Mancini, Ranaldo, and Wrampelmeyer, 2016). The same argument explains, why there is lower activity and small special repo spreads before the start of the three-year LTROs. Specialness is significantly higher, as liquid securities obtain a lower haircut at the Eurosystem, which is more valuable, if the bank can obtain a larger amount of central bank long-term financing.

VSTOXX measuring uncertainty in financial markets lowers daily volume, which can be interpreted as a form of rationing. Investors trade the bond at the same daily frequency, but at lower volumes. Higher specialness indicates that the premium of trading specific securities rises. In combination with the notion that more liquid securities go more often on special (Duffie, 1996), those results reflect a flight-to-liquidity, which occurs during market stress (Beber, Brandt, and Kavajecz, 2009). Investors are more risk-averse and are willing to pay a premium to obtain a liquid security (Vayanos, 2004).

[24] As a robustness check, I run the same regressions only for the period of full allotment. In the case of full allotment, the results are qualitatively the same. Results are available upon request from the author.

[25] Since the measure of specialness depends on the matching used, the regression is performed for the use of different GC rates, and the one-week unsecured rate, Euribor (as shown in Chapter 1, there is a close relationship between unsecured and secured rates.). Table 2.5 shows the results. The conclusions drawn do not change, when using different types of matching. In the regression with the Euribor, the results of *changecbpp2* and *changepspp* are different, which might be due to a separate effect of those programmes on the unsecured rate than the secured rate. In Chapter 1 it is also revealed that there can be circumstances, when the repo and unsecured rate move independently from another.

The asset purchase programmes by the Eurosystem tend to decrease activity in the special repo market and to reduce specialness. Corradin and Maddaloni (2015) find that specialness increases for Italian bonds, when the Eurosystem starts to buy government bond securities of troubled countries (SMP). There are two conditions for this effect to occur. First, those bonds must become scarcer in the cash and special repo market. Second, the GC rate for those bonds decreases less than their special repo rates. If the collateral value of those bonds increases, the GC rate will drop as well (Bartolini, Hilton, Sundaresan, and Tonetti, 2011). The distance between the GC rate and the special repo rate determines specialness. The decrease in specialness during the first covered bond purchase programme is due to a significant drop in the GC rate for covered bonds. The GC rate drops significantly during the first covered bond purchase programme.[26] In addition, the purchases by the Eurosystem might lead to a segmented market. Those covered bonds, which are purchased by the ECB, obtain a high specialness premium and the specialness of the other potentially drops. This is in accordance with Trebesch and Zettelmeyer (2016) who show that the Eurosystem SMP purchase programme only affects the yields of bonds they have bought, not the other ones. The PSPP has a similar effect as CBPP1 on the overall special repo market, but special repo spreads tend to be higher. When the frequency regression is run only for government bonds, the coefficient on *changepspp* is insignificant. The frequency does not decrease for those bonds, whereas special repo spreads do, contrary to the positive overall effect. This supports the explanation of market segmentation. At the start of PSPP, there seem to be no spillover effects yet to other assets by means of substitution, i.e. investors purchase cheaper substitutes to those bonds that the Eurosystem is buying (Krishnamurthy, Nagel, and Vissing-Jorgensen, 2017).

All in all, the special repo market reacts strongly to the implementation of Eurosystem policies. The asset purchase programmes have a large impact, but so does the liquidity injection by the Eurosystem, as demonstrated by the effect of *excessliq*. Specialness rises, as these securities can be used to obtain (long-term) central bank liquidity. This has an effect on asset markets. Given that the price of a bond reflects its specialness premium (Duffie, 1996), the prices of bonds are higher in the cash market. The liquidity injection by the Eurosystem has thus wide-ranging effects. In addition, the ECB moves into the territory of negative interest rates. This seems to lower activity in the repo market, which is analyzed further in the next section. It is important, because the special repo is used for market-making in the cash market. The less attractive it is to trade in the special repo market, the more market-making in the cash market might suffer. In the view of efficient markets, less trading opportunities might be used and less information about prices will be available. As the Eurosystem uses market data to determine the collateral values of the bonds pledged, this also potentially lowers the precision of their risk management.

[26]Results from the regression of the GC rate on the independent variables are available on request.

2.4.3 The effect of a negative deposit facility rate on special repo

On June 11, 2014 the ECB introduces a negative rate on its deposit facility, the (effective) policy rate. This decision is made to incentivize banks to lower their cash deposits at the Eurosystem and look for other investment possibilities with the ultimate goal of stimulating growth.[27] The policy rate changes from 0.00 to -0.10%. The rate is further lowered to -0.20% on September 10, 2014. Figures 2.1 and 2.2 show the development in the number of transactions of the one-week contracts for the whole sample period and the subsample period May 01, 2014 to December 31, 2014. The two dates of rate changes are marked by black lines. Over the whole sample period the number of transactions varies considerably. The largest increase occurs in 2010. The largest decrease, though, can be seen in 2014. In Figure 2.2 it is apparent that it takes some time until activity declines after the switch to a negative policy rate. At the beginning of July, the number of transactions starts to fall until the end of the year 2014. It is important that no other monetary policy decisions by the ECB are implemented until mid September: the first TLTRO is conducted on September 18, 2014, and CBPP3 in October 2014. Figure 2.3 shows the effect on the special repo rate by type of security around the date of June 11, 2014. Except for three types of securities (EIB, European Corporate, German Pfandbrief), the average volume-weighted special repo rate is above zero before the switch to the negative deposit facility rate. Afterward it is negative for all types of securities.

[insert Figures 2.1, 2.2, and 2.3 about here]

The effect of a negative policy rate is now tested for all dependent variables. The tests focus on the change on June 11, 2014. As in Section 2.4.2, I run separate panel regressions for each dependent variable (*freq*, *logvolume*, *diffrate*, *specialness*). The panel variable is the bond and the time variable is one day. I use three different event windows: one month before and after the switch to a negative rate, two months before and after, and three months before and after. This should allow for a better estimation of this policy change.[28] The sample of bonds is restricted to those that trade before and after the switch to the negative rate. In addition, bonds that mature before the end of the last event window, September 11, 2014, are eliminated as well. In addition to the independent variables *belowzero*, *excessliq*, and *vstoxx* I include in X as further controls dummy variables for the end-of-quarter, lagged futures delivery day, and the weekday. The following regression is

[27] Their decision is justified and explained on http://www.ecb.europa.eu/explainers/tell-me-more/html/why-negative-interest-rate.en.html.

[28] The last window contains the second rate decrease on September 10, 2014.

run:

$$y_{i,t} = \beta_1 + \beta_2 belowzero_{i,t} + \beta_3 vstoxx_{i,t-1} + \beta_4 excessliq_{i,t-1} + X\beta + \varepsilon_{i,t} \quad (2.3)$$

Table 2.6 presents the results. The variable of interest is *belowzero*. Panel A shows the results for the period: May 11–July 11, 2014, Panel B for April 11–August 11, 2014, and Panel C for March 11–September 11, 2014. The frequency of trading special by bond decreases, when the deposit facility rate turns negative. The coefficient on *belowzero* in the shortest time period is not significant, but strongly significant in Panel B and C. In the six-months period, the frequency by bond decreases by 0.11. The effect on volume is significant in the two-months window (Panel A). The daily volume in each bond is 8% lower, when the policy rate becomes negative. This effect gets stronger over time. In the six months-window (Panel C) it is up to 15%. The difference between the special rate and the policy rate decreases with the switch to the negative policy rate. The coefficient is between 1 and 2 bps in each time window and significant at the 5% level. The average specialness also becomes lower. This is the case for all event windows. The coefficient ranges from 3.8 bps (Panel A) to 7 bps (Panel C) at a significance level of 5%. When using the same sample for the special repo spread (*diffrate*), there is no significant change in the latter.

[insert Table 2.6 about here]

The activity in the special repo declines, as evidenced by the figures and the regressions. The number of trades and daily volume in each bond become smaller. The effect strengthens over time, as market participants adjust their trading behavior. This is driven by the fact that in all special repo trades the cash taker/ security giver receives a lower volume than he has provided. Even if the opportunity cost, the specialness, stays constant, this cost is more tangible. This disincentivizes investors and market-makers to use the special repo market. Special repo rates are driven further towards the policy rate, whereas specialness decreases. Market participants now trade in special repo, in all likelihood, when they direly need the security, or when the special repo rate is not that much lower than the GC rate. In order to minimize costs, they try to trade less and/or in securities with a lower specialness.[29] Once banks adjust to the new market environment of negative interest rates, this trend might reverse, of course.

In order to test if there is a difference in cheaper/more expensive securities, I split the sample in two. For the period before June 11, 2014, I compute the average special repo rate for each bond and determine the median. The securities whose special repo rate is above the median are labeled cheap. The securities whose rate are below the median

[29]The repo market is also affected by changes in regulation, Basel III, which make trading in repo more expensive in terms of capital. This supports this trend.

are comparatively expensive.[30] Figures 2.4, 2.5, 2.6, and 2.7 depict the differential effect of both groups on the dependent variables. The blue columns depict periods before the change, the gray patterned columns those after the change. It can be seen that the number of daily trades in cheaper securities is in general higher. After the change to a negative policy rate this number remains constant. It decreases, though, for securities that are on average more expensive (lower special repo rate). The figure displaying volume per transaction shows the reverse. Volumes for cheaper securities decrease per transaction, whereas they remain constant for the more expensive securities. The special repo rates of cheaper securities move closer to the policy rate, but they stay at the same level for more expensive securities as compared to the previous months. This is also reflected in specialness, which falls less for cheap securities than for more expensive securities.

[**insert Table 2.7 about here**]

I test these observations formally by running the same regressions as above for these two subsamples. Table 2.7 reports the results, which confirm the conclusions drawn from the figures. Cheaper securities still trade at the same frequency, but at a lower volume. Expensive securities trade less often, at the same volumes and special repo spreads. The special repo rates of cheaper securities fall relative to the effective policy rate. Specialness declines most for the expensive securities, but also for cheaper securities. Banks now trade less often, which will affect their market-making activities in the cash market.

2.5 Conclusion

Special repo trades are impacted by three different set of drivers: bond characteristics, Eurosystem monetary policy measures and financial market uncertainty. The issue size is a strong determinant of how often a bond trades special. The reason is that the supply of this bond is more easily available. It is safer to short a bond that is in large supply than a bond that has a small outstanding issue. There is also a tendency to trade in bonds that have a longer term. Over time, the special repo market reacts to measures taken by the Eurosystem and expected volatility in the market. Larger expected volatility in the stock market leads to rationing, a lower daily traded volume and larger specialness, which is in line with flight-to-liquidity during market stress.

Three factors by the Eurosystem influence activity in the special repo market, its liquidity injection, its asset purchase programmes and its switch to a negative policy rate. Excess liquidity, which leads to higher values for eligible securities (including those trading on Eurex Repo), tends to decrease the number of trades in the special repo

[30] The deposit facility rate is zero at this point in time, so that *diffrate*is equal to the special repo rate before the change.

market and reduce special repo rates relative to the effective policy rate. A similar effect can be observed before the Eurosystem injects very long-term financing. Before the two three-year LTROs, activity in the special repo market decreases. Specialness is on average higher before these LTROs. Liquid securities, which trade more often on special, are more valuable than illiquid securities, since they obtain a lower haircut at the ECB, and banks can thus receive more long-term central bank financing. The Eurosystem asset purchase programmes tend to decrease activity in the special repo market, with the PSPP (part of Quantitative Easing) being the largest programme. The number of trades declines, special repo spreads drop, and specialness decreases. This is again due to the fact that there is a concentration in special repo on one asset class, i.e. government bonds. For this asset class special repo spreads decrease, whereas they do increase for larger purchase volumes.

The ECB's switch to a negative deposit facility rate on June 11, 2014 lowers the frequency of trades, the daily traded volume in each bond, the special repo spread, and specialness. A negative repo rate makes a repo transaction very unattractive for the security borrower. It effectively reduces the available cash of a bank after the term leg of the transaction has been settled. The aim of the ECB to switch to a negative rate is to force banks to invest their cash in investments with a positive return. It has the negative side effect of reducing the attractiveness of market-making in the cash market. Thus, market liquidity in the cash market is possibly lower, if it is very expensive to cover short positions in the special repo market.[31] This in turn may rise the potential for squeezes in the special repo market, as it becomes more difficult to locate the security.

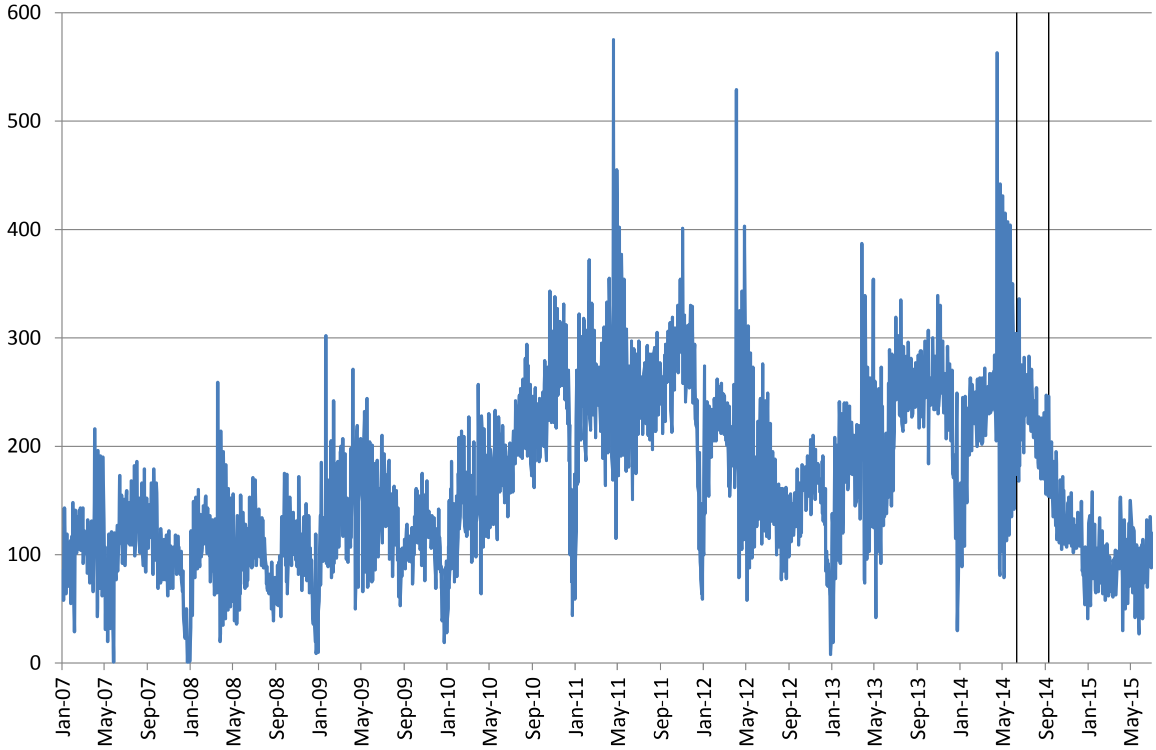
Even though, the special repo market is not the focus of ECB liquidity policy measures, it is indirectly affected. It supports market liquidity in the bond market. If this is impaired, less bond trades might occur and less prices form. Bond prices are important for banks' risk and collateral management. The Eurosystem also determines its collateral values from bond prices. If there is less information available, risk management of banks and the ECB might become less accurate. It is crucial to have an understanding of how financial markets are connected and how they react to different policy measures, in order to have a good basis for policy decisions.

[31]The ongoing implementation of Basel III due to higher capital requirements also impedes trading in repo. This is another factor, why banks might reduce trading in special repo, until they are used to the new market environment.

2.6 Appendix

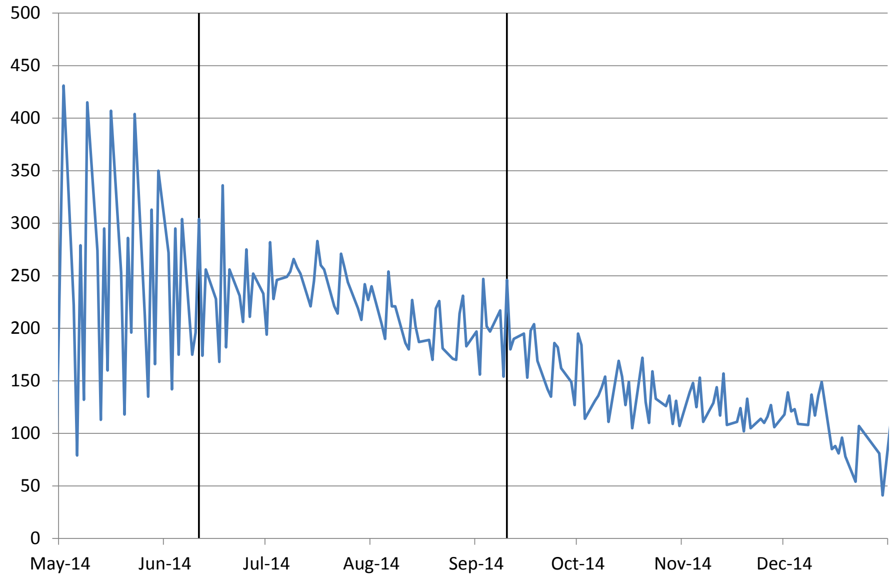
2.6.1 Figures

Figure 2.1: Number of special repo transactions, one-week contracts, Jan 2007 - Jun 2015



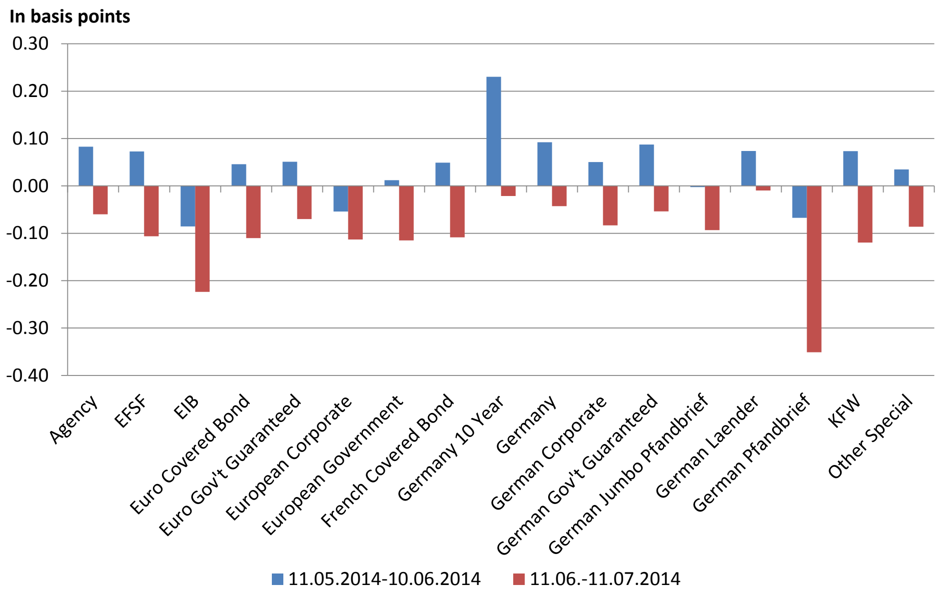
This figure shows the daily number of transactions in the one-week segment in the period January 01, 2007 to June 30, 2015 (source: Eurex Repo). The first black line denotes the switch to a negative policy rate on June 11, 2014. The second black line relates to the following decrease in the deposit facility rate on September 10, 2014.

Figure 2.2: Number of transactions, one-week contracts, May 2014 - Dec 2014



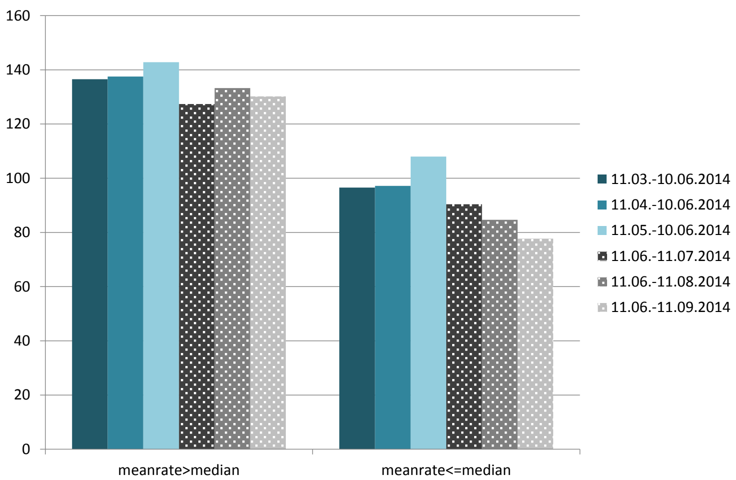
This figure shows the daily number of transactions in the one-week segment in the period May 01, 2014 to December 31, 2014 (source: Eurex Repo). The first black line denotes the switch to a negative policy rate on June 11, 2014. The second black line relates to the following decrease in the deposit facility rate on September 10, 2014.

Figure 2.3: Special repo rate, one-week contracts, volume weighted average



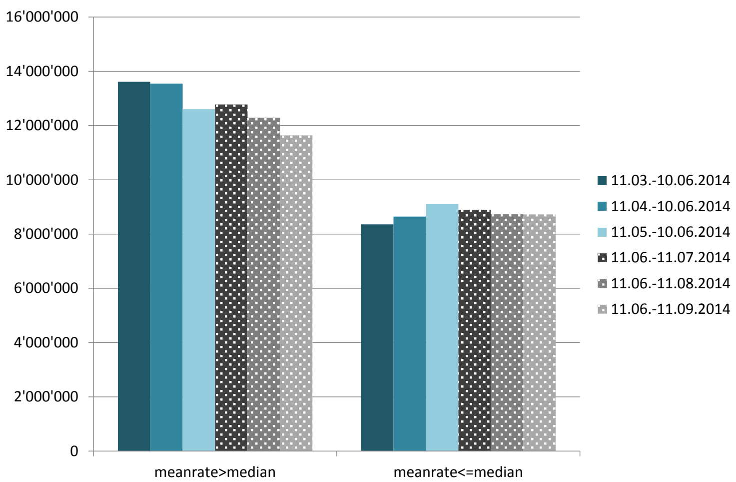
This graph shows the volume-weighted average of the special repo rate in the period in two different time periods for the different types of securities. Securities have to be traded in both time periods and mature after September 11, 2014. The blue bar denotes the period 12 May – 10 June 2014. The red bar is the period 12 June – 11 July 2014. Here I use the repo rate instead of the spread for illustration purposes.

Figure 2.4: Number of trades per day



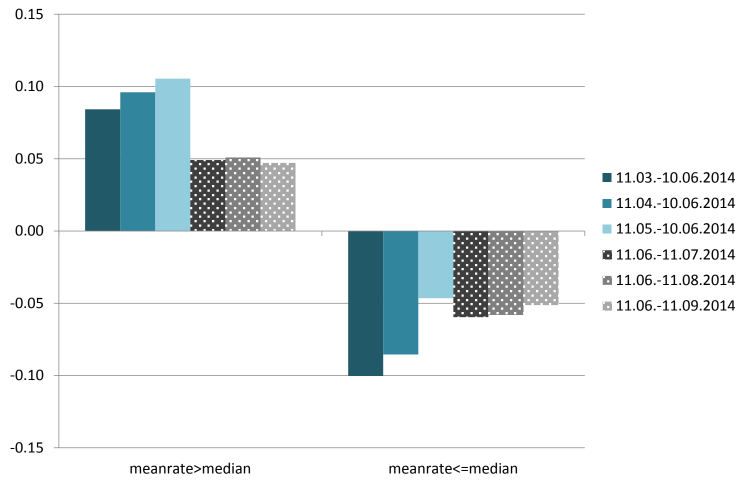
This graph shows the number of trades per day. It compares the number of trades before and after the switch to the negative deposit facility rate. The blue bars show the periods before, and the gray bars the periods after. The securities are split in two samples. The left bars display the changes in trades for those, whose volume-weighted average rate is higher than the median rate of all securities (cheap securities). The right bars represent the securities that have a lower volume-weighted average rate (expensive securities). Securities have to be traded in both time periods and mature after September 11, 2014.

Figure 2.5: Volume by transaction



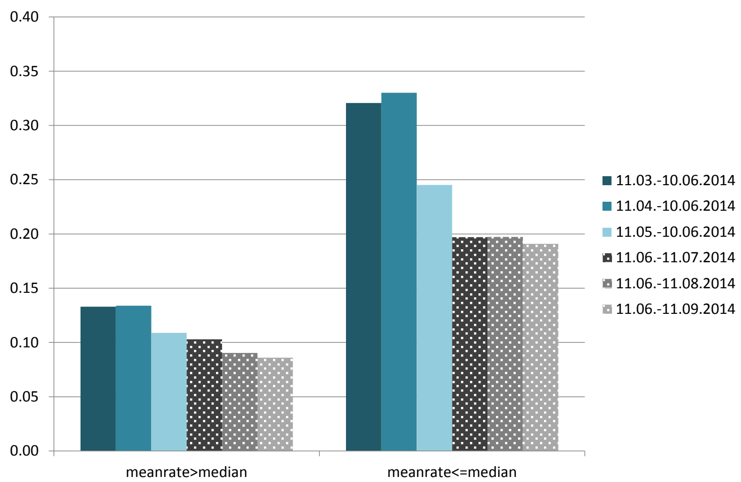
This graph shows the traded volume per day. It compares the volume before and after the switch to the negative deposit facility rate. The blue bars show the periods before, and the gray bars the periods after. The securities are split in two samples. The left bars display the changes in trades for those, whose volume-weighted average rate is higher than the median rate of all securities (cheap securities). The right bars represent the securities that have a lower volume-weighted average rate (expensive securities). Securities have to be traded in both time periods and mature after September 11, 2014.

Figure 2.6: Volume-weighted average special repo spread



This graph shows the volume-weighted average special repo spread per day. It compares the special repo spread (in %) before and after the switch to the negative deposit facility rate. The blue bars show the periods before, and the gray bars the periods after. The securities are split in two samples. The left bars display the changes in trades for those, whose volume-weighted average rate is higher than the median rate of all securities (cheap securities). The right bars represent the securities that have a lower volume-weighted average rate (expensive securities). Securities have to be traded in both time periods and mature after September 11, 2014.

Figure 2.7: Volume-weighted average specialness



This graph shows the volume-weighted average specialness per day. It compares the specialness (in %) before and after the switch to the negative deposit facility rate. The blue bars show the periods before, and the gray bars the periods after. The securities are split in two samples. The left bars display the changes in trades for those, whose volume-weighted average rate is higher than the median rate of all securities (cheap securities). The right bars represent the securities that have a lower volume-weighted average rate (expensive securities). Securities have to be traded in both time periods and mature after September 11, 2014.

2.6.2 Tables

Table 2.1: Descriptive Statistics I

This table presents descriptive statistics on the Eurex Repo data and explanatory variables. The sample spans the time period January 01, 2007 - June 30, 2015. The lower panel displays the sum of traded volume (volume) by type of security on bond level.

	No. Obs.	Mean	St. Error	Median	St. Dev.	Min	Max
Sum Traded Volume in mio. (bond)	3,223	2,750	148	468	8,430	0.9928	155,000
Frequency (bond)	3,223	158.29	4.80	39.00	272.58	1.00	2716.00
Special Rate (bond) in %	3,223	0.60	0.02	0.11	1.17	-2.00	4.34
Specialness (bond) in %	2,428	0.24	0.00	0.20	0.17	0.00	1.90
Traded bonds per day	2,171	157.31	1.07	154.00	49.74	1.00	392.00
Contract Term	510,173	7.61	0.02	7.00	12.49	1.00	480.00
Amount Outstanding (in mio.)	3,214	3,340	96.5	1,490	5,470	25	43,200
Term of bond in years	3,215	7.24	0.09	6.01	5.04	0.25	51.04
VSTOXX	2,171	25.49	0.21	23.08	9.57	12.71	87.51
ExcessLiq (in EUR mio.)	2,170	193,188	4,706	131,662	219,221	-134,833	811,857
Change in vol. CBPP1 (in EUR mio.)	2,170	28.18	2.04	0.00	95.25	0.00	803.00
Change in vol. CBPP2 (in EUR mio.)	2,171	7.55	0.79	0.00	36.93	0.00	704.00
Change in vol. CBPP3 (in EUR mio.)	2,170	214.62	16.34	0.00	761.18	-28.00	5,078.00
Change in vol. PSPP (in EUR mio.)	2,170	442.54	49.45	0.00	2,303.42	0.00	16,549.00
Traded volume by type in EUR million							
Agency	243	3,020	421	332	6,560	1	50,900
Austrian government	5	2,290	1,150	887	2,580	10	5,720
Belgian government	12	450	145	318	503	36	1,720
Dutch government	9	988	221	845	664	24	2,040
EFSF	66	1,630	345	250	2,800	2	12,200
EIB / KFW	34	3,230	669	1,990	3,900	14	20,000
EIB	16	3,650	922	3,080	3,690	2	12,500
Euro covered bond	571	1,790	108	1,120	2,570	1	28,600
Euro gov't guaranteed	77	1,890	414	247	3,640	1	14,500
European corporate	394	167	22	41	434	1	4,660
European government	195	2,080	226	1,040	3,160	3	31,900
Finnish government	2	939	901	939	1,270	38	1,840
French covered bond	136	1,230	110	772	1,290	8	7,720
French government	26	1,030	192	726	981	50	3,630
Germany 10 year	118	6,300	771	1,440	8,370	2	40,200
Germany	79	34,400	3,940	21,500	35,000	31	155,000
German Corporate	56	709	145	124	1,090	2	4,850
German KfW / Laender	385	2,090	159	831	3,130	1	24,400
German gov't guaranteed	50	4,780	632	3,530	4,470	27	19,200
German Jumbo Pfandbrief	289	2,970	211	1,950	3,590	2	22,000
German Laender	179	1,100	131	570	1,750	1	14,000
German Pfandbrief	89	418	81	154	767	1	5,940
KFW	5	6,720	2,680	7870	5,990	287	14,000
Spanish government	5	183	60	128	135	94	420
Other special	589	544	106	59	2570	1	41,400

Table 2.2: Descriptive Statistics II

This table presents average figures by type of security. For all statistics on bond level, first the number was calculated for each bond and then the average was calculated. Specialness was calculated as the volume-weighted average for each bond, and then the average was taken. The sample period is January 01, 2007 to June 30, 2015.

Average figures	bond level	bond level	transaction level	bond level	bond level
	Frequency total #	Specialness in %	Contract Term days	Amount Outst. in EUR mio.	Term of bond years
Agency	219.56	0.29	7.39	2,810	5.92
Austrian government	15.00	NA	11.69	8,190	10.42
Belgian government	3.50	NA	23.69	8,300	7.89
Dutch government	8.00	NA	10.18	14,900	9.39
EFSF	116.26	0.20	7.25	3,400	3.11
EIB / KFW	227.68	0.21	7.01	4,470	7.36
EIB	293.50	0.36	7.13	3420	13.01
Euro covered bond	191.00	0.22	7.48	1,520	7.50
Euro gov't guaranteed	146.99	0.22	7.27	2,620	7.43
European corporate	24.17	0.30	8.25	1,270	6.54
European government	59.30	0.19	9.56	14,600	13.02
Finnish government	7.50	1.42	13.20	4,750	13.15
French covered bond	164.61	0.24	7.44	1,460	7.79
French government	4.12	0.10	6.07	18,300	5.79
Germany 10 year	69.43	0.11	7.29	10,600	2.50
Germany	343.78	0.15	7.28	17,100	12.22
German corporate	31.20	0.20	14.00	997	6.64
German KfW / Laender	218.53	0.25	7.47	1,560	6.36
German gov't guaranteed	293.80	0.16	7.23	3,410	6.85
German Jumbo Pfandbrief	350.45	0.22	7.42	1,560	7.05
German Laender	61.83	0.17	9.65	1,050	8.26
German Pfandbrief	66.93	0.35	7.76	451	6.61
KFW	471.40	0.13	7.41	3,800	4.45
Spanish government	1.00	NA	50.60	16,500	17.28
Other special	26.98	0.24	9.25	1,680	7.32

Table 2.3: Cross-sectional regressions

This table presents cross-sectional regressions on bond characteristics. *freq* is the total number of transactions per trading day in one bond in the time period January 01, 2007 to June 30, 2015. *logvolume* is the natural log of the average transaction volume in EUR over the sample period. *diffrate* is calculated as the difference between the special repo rate and the effective policy rate. Until October 08, 2008, the effective policy rate is the minimum bid rate in the weekly Eurosystem liquidity auctions. Thereafter, it is the interest rate on the deposit facility. *diffrate* is the volume-weighted average over the sample period. *specialness* is equal to the GC rate - special repo rate. It is the volume-weighted average over the sample period. The main three independent variables are *logissuesize*, *age* and *term*. *logissuesize* is the natural log of the amount issued of each security. *age* is the average age of a bond calculated across all transactions. *term* is the term of the bond, the number of years between issuance and redemption. The regression contains dummy variables for each type of security (not displayed here). One bond can belong to more than one type. Huber-White robust standard errors are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Whole sample period				Period 2007			
	freq	logvolume	diffrate	specialness	freq	logvolume	diffrate	specialness
constant	-1.3298***	7.6260***	-1.1767***	1.5144***	-1.1053***	8.8257***	-1.3430***	2.1378***
	(0.1448)	(1.0049)	(0.1521)	(0.1531)	(0.3115)	(1.3948)	(0.1595)	(0.2803)
logissuesize	0.0643***	0.3874***	0.0518***	-0.0606***	0.0521***	0.2717***	0.0494***	-0.0574***
	(0.0071)	(0.0479)	(0.0072)	(0.0072)	(0.0147)	(0.0665)	(0.0076)	(0.0120)
age	-0.0069***	0.0147	0.0041**	-0.0008	-0.0046*	-0.0464***	0.0004	-0.0023
	(0.0013)	(0.0101)	(0.0017)	(0.0016)	(0.0026)	(0.0134)	(0.0017)	(0.0025)
term	0.0038***	0.0124**	-0.0033***	0.0024**	0.0026**	0.0133	-0.0001	-0.0004
	(0.0009)	(0.0053)	(0.0009)	(0.0010)	(0.0011)	(0.0097)	(0.0007)	(0.0010)
No. Obs.	2,773	2,773	2,773	2,425	648	648	648	554
R-Squared	0.3443	0.3833	0.1085	0.1359	0.1644	0.3739	0.2641	0.1521

Table 2.4: Fixed effects regressions

This table presents panel regressions. They are estimated with fixed effects on bond level. *freq* is the number of transactions in one bond in one day. *logvolume* is the natural log of the daily transaction volume in EUR. *diffrate* is calculated as the difference between the special repo rate and the effective policy rate. It is the daily volume-weighted average. Until October 08, 2008, the policy rate is the minimum bid rate in the weekly Eurosystem liquidity auctions. Thereafter, it is the interest rate on the deposit facility. *specialness* is equal to the GC rate - special repo rate. It is the daily volume-weighted average. A definition of the independent variables can be found in Sections 2.4.1 and 2.4.1. The regression also includes as controls the rate on the deposit facility, dummies for quarter-end, year-end, weekdays and three lags of the future delivery days. Standard errors clustered on bond level are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	freq	logamount	diffrate	specialness
constant	-0.0616**	0.3734***	0.1348***	-0.4186***
	(0.0312)	(0.0426)	(0.0093)	(0.0326)
belowzero	-0.1265***	-0.0047	-0.0254***	-0.0023
	(0.0187)	(0.0281)	(0.0050)	(0.0054)
excessliq$_{t-1}$	-0.0001***	0.0000	-0.0005***	0.0001***
	(0.0000)	0.0000	(0.0000)	(0.0000)
vstoxx$_{t-1}$	0.0008	-0.0024***	-0.0116***	0.0031***
	(0.0007)	(0.0008)	(0.0004)	(0.0003)
cbpp1announce	-0.0337	-0.1232	-0.0639***	-0.0960***
	(0.0885)	(0.1256)	(0.0195)	(0.0189)
cbpp2announce	-0.0137	0.1389	0.0976***	-0.0865***
	(0.0794)	(0.0918)	(0.0180)	(0.0174)
cbpp3announce	-0.0108	-0.2354*	0.0276	0.0183
	(0.0876)	(0.1372)	(0.0180)	(0.0183)
psppannounce	-0.2201***	-0.3318**	0.0160	0.0486***
	(0.0660)	(0.1448)	(0.0149)	(0.0168)
changecbpp1	-0.1050**	-0.0226	-0.1657***	-0.1847***
	(0.0509)	(0.0698)	(0.0142)	(0.0126)
changecbpp2	-0.1151	-0.5256***	-0.0945**	-0.0580
	(0.0837)	(0.1245)	(0.0451)	(0.0527)
changecbpp3	-0.0049	0.0102	0.0106**	0.0038
	(0.0114)	(0.0195)	(0.0044)	(0.0046)
changepspp	-0.0059***	-0.0011	0.0032***	-0.0028***
	(0.0021)	(0.0034)	(0.0005)	(0.0005)
before1year	0.0269	-0.0688*	0.1348***	0.1654***
	(0.0287)	(0.0352)	(0.0087)	(0.0083)
beforeltro1	-0.0830***	-0.0935***	-0.1785***	0.0785***
	(0.0223)	(0.0264)	(0.0087)	(0.0144)
beforeltro2	-0.0146	-0.1082***	-0.1813***	0.1155***
	(0.0197)	(0.0264)	(0.0051)	(0.0069)
fullallot	0.0633*	-0.3743***	0.2247***	0.5163***
	(0.0348)	(0.0475)	(0.0072)	(0.0302)
No. Obs.	254,155	254,155	254,155	116,122
R-Squared	0.0021	0.0069	0.2559	0.1696

Table 2.5: Robustness check: results of specialness regression with different matching

This table presents panel regressions for different measures of specialness. The regressions are estimated with fixed effects on bond level. *specialness* is equal to the GC rate - special repo rate. It is the daily volume-weighted average on transaction day. The GC rate chosen is the volume-weighted average GC rate of the same type of security, the same purchase day and the term of one week. If there is no match for a covered bond, the volume-weighted average GC rate for all covered bonds trading on that day is used. After this matching, the pooled GC rate for all types of securities is used instead. The first column represents this matching methodology, which is used in Table 2.4. The second column shows the results of this regression, when only the GC rate of the same type or the GC rate of covered bonds is used. The third column displays the results for the panel, if only the GC rate of the same type is taken. The fourth column shows the results for the subsample, for which the GC pooled rate was applied. The next column displays the results, if the pooled GC rate was used for the whole sample. The last column uses the one-week Euribor as benchmark, i.e. Euribor - special repo rate (since in Chapter 1 we show that the GC repo rate and unsecured rate are strongly interconnected). A definition of the independent variables can be found in Sections 2.4.1 and 2.4.1. The regression also includes as controls the rate on the deposit facility, dummies for quarter-end, year-end, weekdays and three lags of the future delivery days. Standard errors clustered on bond level are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Benchmark	Subsample	Subsample	Subsample	Other match 1	Other match 2
	GC Pooled, GC cov, GC rate	GC cov, GC rate	GC rate	GC Pooled (subsample)	GC Pooled (full sample)	Euribor
constant	-0.4186***	-0.4407***	-0.4650***	-0.4156***	-0.4222***	-0.6271***
	(0.0326)	(0.0356)	(0.0343)	(0.0360)	(0.0300)	(0.0297)
belowzero	-0.0023	-0.0205	-0.0038	-0.0023	-0.0018	-0.0190***
	(0.0054)	(0.0136)	(0.0164)	(0.0056)	(0.0054)	(0.0050)
excessliq_{t-1}	0.0001***	0.0000*	0.0000*	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
vstoxx_{t-1}	0.0031***	0.0056***	0.0053***	0.0022***	0.0029***	0.0053***
	(0.0003)	(0.0006)	(0.0006)	(0.0003)	(0.0003)	(0.0002)
cbpp1announce	-0.0960***			-0.1063***	-0.0933***	-0.0539***
	(0.0189)			(0.0191)	(0.0190)	(0.0186)
cbpp2announce	-0.0865***			-0.0666***	-0.0799***	0.0102
	(0.0174)			(0.0178)	(0.0173)	(0.0164)
cbpp3announce	0.0183			0.0208	0.0194	0.0177
	(0.0183)			(0.0179)	(0.0182)	(0.0165)
psppannounce	0.0486***	0.1151***	0.1101***	0.0499***	0.0486***	0.0395
	(0.0168)	(0.0106)	(0.0121)	(0.0180)	(0.0168)	(0.0144)
changecbpp1	-0.1847***	-0.2673***	-0.3053***	-0.1979***	-0.1827***	-0.3629***
	(0.0126)	(0.0171)	(0.0205)	(0.0141)	(0.0125)	(0.0131)
changecbpp2	-0.0580	-0.0743	-0.1530	0.0141	-0.0521	0.2365***
	(0.0527)	(0.00911)	(0.0971)	(0.0527)	(0.0529)	(0.0429)
changecbpp3	0.0038	-0.0077	-0.0117	0.0058	0.0043	0.0041
	(0.0046)	(0.0134)	(0.0159)	(0.0044)	(0.0045)	(0.0045)
changepspp	-0.0028***	-0.0052**	-0.0080***	-0.0025***	-0.0028***	-0.0006
	(0.0005)	(0.0021)	(0.0026)	(0.0005)	(0.0005)	(0.0004)
before1year	0.1654***	0.1209***	0.1201***	0.1937***	0.1675***	0.1369***
	(0.0083)	(0.0106)	(0.0106)	(0.0106)	(0.0083)	(0.0083)
beforeltro1	0.0785***	0.3337***	0.3337***	0.0581***	0.0857***	0.3260***
	(0.0144)	(0.0549)	(0.0547)	(0.0150)	(0.0144)	(0.0089)
beforeltro2	0.1155***	0.2250***	0.1989***	0.0947***	0.1099***	0.1809***
	(0.0069)	(0.0211)	(0.0206)	(0.0071)	(0.0069)	(0.0054)
fullallot	0.5163***	0.5026***	0.5312***	0.5274***	0.5210***	0.7270***
	(0.0302)	(0.0382)	(0.0380)	(0.0329)	(0.0302)	(0.0275)
No. Obs.	116,122	26,179	23,283	92,850	116,122	253,820
R-Squared	0.1696	0.202	0.2051	0.1578	0.1682	0.3469

Table 2.6: Change to a negative policy rate

This table presents panel regressions estimated around the date of switch to a negative policy rate, June 11, 2014. They are run with fixed effects on bond level. The sample only contains bonds that are traded before and after the switch to a negative rate and that mature after September 11, 2014. The independent variable of interest is *belowzero*, a dummy variable that is equal to zero starting the day of June 11, 2014. *freq* is the number of transactions in one bond in one day. *logvolume* is the natural log of the daily transaction volume in EUR. *diffrate* is calculated as the daily volume-weighted average difference between the special repo rate and the effective policy rate. Until October 08, 2008, the effective policy rate is the minimum bid rate in the weekly ECB liquidity auctions. Thereafter, it is the interest rate on the deposit facility. *specialness* is equal to the GC rate - special repo rate. It is the daily volume-weighted average. A definition of the independent variables can be found in sections 2.4.1 and 2.4.1. The regression also includes dummies for quarter-end, weekdays and three lags of the future delivery days. Standard errors clustered on bond level are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

Panel A	*11.05.-11.07.2014*			
	freq	logvolume	diffrate	specialness
constant	0.1643	0.3960**	-0.0717***	0.3709***
	(0.1422)	(0.1714)	(0.0208)	(0.0453)
belowzero	-0.0492	-0.0786**	-0.0132**	-0.0383***
	(0.0347)	(0.0374)	(0.0062)	(0.0091)
vstoxx_{t-1}	0.0010	-0.0112	0.0081***	-0.0077***
	(0.0095)	(0.0107)	(0.0013)	(0.0021)
excessliq_{t-1}	-0.0014***	-0.0006	-0.0004***	-0.0005***
No. Obs.	6,135	6,135	6,135	2,399
R-Squared	0.0135	0.0180	0.0104	0.0227
Panel B	*11.04.-11.08.2014*			
constant	0.2193**	0.3539***	0.0070	0.2566***
	(0.1005)	(0.1212)	(0.0090)	(0.0261)
belowzero	-0.1018***	-0.1155***	-0.0172***	-0.0663***
	(0.0346)	(0.0371)	(0.0059)	(0.0077)
vstoxx_{t-1}	-0.0024	-0.0033	0.0016**	-0.0006
	(0.0055)	(0.0066)	(0.0006)	(0.0013)
excessliq_{t-1}	-0.0013***	-0.0012***	-0.0003***	-0.0002*
	(0.0003)	(0.0003)	(0.0000)	(0.0001)
No. Obs.	11,363	11,363	11,363	4,274
R-Squared	0.0150	0.0149	0.0030	0.0394
Panel C	*11.03.-11.09.2014*			
constant	0.3096***	0.3941***	0.0126	0.3082***
	(0.0899)	(0.1114)	(0.0128)	(0.0228)
belowzero	-0.1147***	-0.1471***	-0.0118**	-0.0698***
	(0.0305)	(0.0361)	(0.0051)	(0.0055)
vstoxx_{t-1}	-0.0090*	-0.0088	0.0004	-0.0034***
	(0.0047)	(0.0060)	(0.0008)	(0.0012)
excessliq_{t-1}	-0.0011***	-0.0009**	-0.0002***	-0.0002***
	(0.0003)	(0.0003)	(0.0000)	(0.0001)
No. Obs.	17,808	17,808	17,808	5,859
R-Squared	0.0110	0.0103	0.0008	0.0428

Table 2.7: Differential effect

This table presents panel regressions estimated around the date of switch to a negative policy rate, June 11, 2014. They are run with fixed effects on bond level. The sample only contains bonds that are traded before and after the switch to a negative rate and that mature after September 11, 2014. The independent variable of interest is *belowzero*, a dummy variable that is equal to zero starting the day of June 11, 2014. Each cell reports the coefficient on *belowzero*. The regression also includes the lagged VSTOXX, the lagged excess liquidity, dummies for quarter-end, weekdays, and three lags of the future delivery days. *freq* is the number of transactions in one bond in one day. *logvolume* is the natural log of the daily transaction volume in EUR. *diffrate* is calculated as the daily volume-weighted average difference between the special repo rate and the effective policy rate. Until October 08, 2008, the policy rate is the minimum bid rate in the weekly Eurosystem liquidity auctions. Thereafter, it is the interest rate on the deposit facility. *specialness* is equal to the GC rate - special repo rate. It is the daily volume-weighted average. Standard errors clustered on bond level are in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	meanrate>median (bond)	meanrate≤median (bond)
	freq	freq
11.05.-11.07.2014	-0.0207	-0.0811
	(0.0476)	(0.0511)
11.04.-11.08.2014	-0.1009*	-0.1060**
	(0.0516)	(0.0416)
11.03.-11.09.2014	-0.0931**	-0.1478***
	(0.0425)	(0.0407)
	logvolume	logvolume
11.05.-11.07.2014	-0.1137**	-0.0301
	(0.0514)	(0.0547)
11.04.-11.08.2014	-0.1786***	-0.0337
	(0.0504)	(0.0547)
11.03.-11.09.2014	-0.2194***	-0.0425
	(0.0489)	(0.0522)
	diffrate	diffrate
11.05.-11.07.2014	-0.0314***	0.0092
	(0.0061)	(0.0114)
11.04.-11.08.2014	-0.0353***	0.0072
	(0.0026)	(0.0135)
11.03.-11.09.2014	-0.0322***	0.0183
	(0.0023)	(0.0116)
	specialness	specialness
11.05.-11.07.2014	-0.0085	-0.0735***
	(0.0066)	(0.0185)
11.04.-11.08.2014	-0.0474***	-0.0940***
	(0.0035)	(0.0184)
11.03.-11.09.2014	-0.0519***	-0.0991***
	(0.0031)	(0.0130)

3 Frictions in the Interbank Market: Evidence from Volumes

3.1 Introduction

Recently it has become clear that the interbank market functions less well than one may have thought prior to the crisis. Given the fact that liquidity positions by banks matter for their bidding at Eurosystem's auctions (Bindseil, Nyborg, and Strebulaev, 2009), it suggests that liquidity allocation in the interbank market is often not perfectly efficient. In understanding the function of the interbank market it is important to note that it consists of several segments, i.e. the unsecured and the secured market, and as a fallback option there are the standing facilities by the Eurosystem (spearheaded by the European Central Bank).[1] The interbank market has to function well for the efficient distribution of liquidity, insuring banks against liquidity shocks such as large deposit withdrawals (Bhattacharay and Gale, 1987).[2] Frictions may impede the efficient reallocation of liquidity in the interbank market, resulting in liquidity shortages to banks and potentially ending in insolvencies (Rochet and Vives, 2004). The preeminent friction in the interbank market is aggregate credit risk in the banking sector. This goes hand in hand with the uncertainty about the credit risk of a single bank (Heider, Hoerova, and Holthausen, 2015). A less known friction than credit risk is short squeezing (Nyborg and Strebulaev, 2004), i.e. banks that are short of funds being squeezed by other banks. In addition, the interbank market is exposed to conditions in other financial markets (e.g. stock market) in which banks trade their assets (Brunnermeier and Pedersen, 2009). Overall, frictions may cause allocational inefficiencies in the interbank market: despite aggregate sufficient liquidity, banks who need the liquidity the most are not able to obtain it or just at very high costs.

Understanding these frictions and their impact on liquidity allocation in the interbank market, especially in different periods of stress, is therefore important. If a friction lowers trading activity in the interbank market or raises volumes at the standing facilities, this

[1]As an alternative to the interbank market banks can access the standing facilities to obtain or deposit liquidity at the Eurosystem (spearheaded by the ECB) at a cost (Section 3.3.1). The ECB decides on monetary policy measures that are implemented by the Eurosystem, which comprises of the national central banks and the ECB.

[2]The interbank market is also important as channel for the distribution of credit to companies, and thus may affect the cost of capital to firms (Bernanke and Gertler, 1995), but this function is not the focus here.

suggests that the allocation works less smoothly. In this paper I analyze the impact of frictions on traded volumes in two segments of the interbank market and the use of the Eurosystem standing facilities. In addition, I provide several stylized facts of what happened during the crisis in the European interbank market. The two segments examined are the overnight unsecured market (Eonia)[3] and one electronic overnight secured market (GC Pooling). Transactions in GC Pooling are operated on Eurex Repo's trading platform and cleared by the Central Counterparty (CCP) Eurex Clearing. The use of the standing facilities reflect the general state of the interbank market and thus complement the analysis of the secured and unsecured market. The time period studied is March 17, 2004 to November 30, 2011. This includes the financial crisis, in which the impact of frictions changes due to banks becoming more alert to risks in financial markets and the switch in the Eurosystem's institutional framework to full allotment, i.e. the Eurosystem injects as much liquidity as banks demand.

The frictions that are important in this setting (in Section 3.2) are squeezing, credit risk, uncertainty about a single bank's risk, and expected volatility in the stock market. Interbank market data as well as the data for friction measures were retrieved from Bloomberg. Data on Eurosystem liquidity operations, reserve maintenance periods and the use of the standing facilities was obtained from the ECB webpage. In addition, I study the effect of institutional factors, since they affect banks' supply and demand for interbank market exposures.

The Eurosystem's operational framework for monetary policy shapes the Euro area interbank market. It displays several calendar day regularities that have been studied so far primarily in rates (Hamilton (1996) in the US, Fecht, Nyborg, and Rocholl (2008), Nautz and Offermanns (2008) in the Euro area). Munyan (2015) documents seasonality in repo volumes at quarter- and year-end in the US, which are also accounted for in this study. Likewise, which is explored in this paper, trading volumes display patterns that stem from the Eurosystem institutional framework and end-of-quarter effects. A study of those calendar day effects helps to better understand the role of the interbank market in banks' liquidity management and the importance of regulations on liquidity allocation in the interbank market.

As a first step, I run daily time series regressions of volumes on dummy variables capturing calendar day effects. Three time periods are considered, before the crisis (March 17, 2004, – July 31, 2007), first stage of the crisis (August 09, 2007 – September 12, 2008) and after full allotment (October 09, 2008 – November 30, 2011). I find evidence that there are calendar day effects stemming from the periodicity of the Eurosystem's liquidity operations in Eonia volumes and in the use of the standing facilities, i. e. volumes increase

[3]Eonia denotes the overnight unsecured interbank interest rate. My focus is on volumes and when referring to the Eonia market I mean the volumes traded overnight.

on the last days of the maintenance period.[4] There is a strong end-of quarter effect in volumes, i.e. interbank market volumes, Eonia and GC Pooling, are lower, whereas volumes at the standing facilities (except for the period of full allotment) are higher. This is due to balance sheet reporting at the end of the quarter (Gropp and Heider, 2010). Trading activity at the end of maintenance period changes during the sample period. Before the start of the crisis, there is higher interbank activity at the end of the maintenance period, but also high volumes at the standing facilities, which implies that there is demand and supply for liquidity that does not meet in the interbank market, which is allocationally not efficient. Due to a more accommodative liquidity stance by the Eurosystem, calendar day effects in the last week of the maintenance period weaken in the first stage of the crisis. The change to full allotment by the Eurosystem reverses this effect as compared to the pre-crisis period. At the end of the maintenance period, volumes at the standing facilities and in the Eonia market are lower (and unchanged for GC Pooling). This analysis reveals that trading patterns in the interbank market strongly depend on institutional factors. At the end of the quarter, banks typically avoid interbank market exposures. The end-of-maintenance period effect depends on the supply of central bank liquidity. The more accommodative the supply is, the lower is the risk of a lack of liquidity, and the need to trade in the interbank market.

The analysis of frictions is set within the framework of the Eurosystem monetary operations to accurately capture the links between volumes and frictions. Daily volumes and friction measures are transformed into weekly averages ranging from one liquidity providing monetary auction to the next one. The sample spans the same time periods as the calendar day regressions (March 17, 2004 – November 30, 2011), but the only breakpoint used in this analysis is the collapse of Lehman Brothers and the subsequent switch to full allotment. I perform time series regressions of volumes on my measures of frictions.

Before Lehman, I find evidence for the impact of frictions on the allocational efficiency of the interbank market. Volumes react to frictions, pointing towards disruptions in the interbank market. Credit risk raises volumes in both of the analyzed segments of the interbank market, Eonia and GC Pooling. Given that both markets are overnight, this is possibly due to shifts in volumes from long-term to short-term maturities in interbank loans, implying that long-term loans are reduced (European Central Bank 2008). There is also evidence for market segmentation in the unsecured market, which has lower volume when the market is able to differentiate between riskier and safer banks. Before Lehman, the expected volatility in the stock market positively affects the use of the standing facilities, in particular the deposit facility, and trading in GC Pooling, supporting the notion

[4]The reserve maintenance period has a length of four to six weeks, and is the period, in which banks have to fulfill their reserve requirements, as determined by the Eurosystem (European Central Bank 2002).

of precautionary liquidity hoarding (Acharya and Merrouche, 2012) and the necessity to trade in an anonymous market. Squeezing never materializes because the Eurosystem allocates more credit when banks bid more aggressively. Interest rate spreads actually tend to decrease after an aggressively bid auction.

In the period of full allotment, the impact of frictions on interbank market volumes should be minimal, since the Eurosystem now provides unlimited liquidity.[5] There is evidence, though, of a significant impact of credit risk and market segmentation on volumes. Standing facilities react to credit risk, and the lending facility positively to expected volatility. A rise in credit risk is followed by a larger liquidity uptake in the next Eurosystem's monetary operation. All of the latter imply that precautionary liquidity hoarding still seems to play a role and the overall availability of bank loans has decreased. In the GC Pooling market, trading volume reacts positively to the uncertainty about a bank's risk, but reactions to any other friction measure cannot be observed. This indicates that in this period banks identified as riskier may still lose access to some funding sources and thus obtain more liquidity from GC Pooling, which allows for anonymous trading. All in all, the impact of frictions on trading in the interbank market is still strong, also after the unlimited supply provided by the Eurosystem, implying that this supply of central bank money is necessary.

In general, volumes tend to shift from risky markets to less risky markets in each period. At first, maturities in the interbank market are shortened (European Central Bank 2008), so volumes in the overnight interbank market rise. After the collapse of Lehman Brothers, volumes in the unsecured market are lower and higher in GC Pooling. When credit risk rises in this period, volumes shift towards the deposit facility. As stated above, the sensitivity of banks towards risk has increased after Lehman Brothers. So despite the Eurosystem's liquidity insurance, banks' reaction towards risk can still be observed. This shows that if there are severe frictions in the interbank market, it is difficult to alleviate these solely by central bank liquidity. The functioning of the interbank market depends on the financial health of its participants.

This paper is directly linked to the strand of literature that deals with the characteristics of the interbank market. One of the main building blocks of my analysis is Heider, Hoerova, and Holthausen (2015)'s model on the unsecured interbank market. Other models on the interbank market exist, which explain its features (Freixas and Jorge, 2008; Hauck and Neyer, 2014; Heider and Hoerova, 2009). Empirical evidence on the interbank market is provided by Afonso, Kovner, and Schoar (2011), Copeland, Martin, and Walker (2014) and Krishnamurthy, Nagel, and Orlov (2014) in the US, and by Abbassi, Bräuning, Fecht, and Peydró (2014) and Mancini, Ranaldo, and Wrampelmeyer (2016) in Europe.

[5]In this period the hypothesis of squeezing cannot be studied because the Eurosystem has abandoned its liquidity-neutral policy (Nyborg, Bindseil, and Strebulaev, 2002), i.e. it injects only the amount of liquidity allows banks to fulfill on average their reserve requirements during the maintenance period.

The latter find that the repo platform GC Pooling acts as a risk buffer in times of stress. The stabilizing role of the repo market is predicted by Heider and Hoerova (2009)'s model. The role of GC Pooling as reliable liquidity source is confirmed in my results. Further, I show that trading in an anonymous repo market becomes attractive when volatility in the stock market rises. Dunne, Fleming, and Zholos (2013) study the link between Eurosystem auction and interbank market activity. They use data on BrokerTec, another European repo trading platform. They find substitution between central bank and repo liquidity in the Euro area before the change to full allotment, but not afterwards. This stands in contrast to my results, but their database is different from mine. Moreover, I combine the analysis of the secured overnight market with the analysis of the unsecured market and the use of the standing facilities.

In addition to papers investigating developments of the interbank market during the crisis, this paper is related to the strand of literature that studies the characteristics of the repo market. The first important contribution to repo markets is made by Duffie (1996). He develops a model that connects the prices of bonds to their repo specialness. Specialness will increase their prices, ceteris paribus. Further contributions to the determinants of the repo rate are made by Jordan and Jordan (1997), Bartolini, Hilton, Sundaresan, and Tonetti (2011) and Buraschi and Menini (2001). There is a discussion about the role of repo during the financial crisis. Gorton and Metrick (2011) argue that there has been a run on repo, which is disputed by Krishnamurthy, Nagel, and Orlov (2014). Copeland, Martin, and Walker (2014) find systematic differences between runs in the bilateral and the triparty repo market. The model by Martin, Skeie, and von Thadden (2014) contributes to this discussion, showing in a model based on Diamond and Dybvig (1983) that the bilateral repo market is more robust than the triparty market in the US. One feature of banks during the financial crisis is liquidity hoarding„ which also features in my analysis. Liquidity hoarding is predicted by Caballero and Simsek (2010)'s model on the complexity in the financial sector. Empirical evidence is provided by Acharya and Merrouche (2012) who study the liquidity management of banks in the UK before and during the financial crisis. They find that during the crisis banks started to hoard liquidity, which also led to an increase in overnight interbank rates.

This paper further contributes to the literature on financial stability and financial markets' connectedness starting with Kiyotaki and Moore (1997), who look at the interaction of credit limits and asset prices. They find that small shocks can have perturbing effects on output and asset prices via feedback loops. In this respect, Holmstrom and Tirole (1998) discover that the government has a role in stabilizing asset markets. Diamond and Rajan (2011) create a model, in which banks start hoarding liquidity to protect themselves from potential asset fire sales.

The rest of this paper is organized in the following way. Section II develops the main hypotheses. Section III gives background information on the structure of the interbank market and its exposure to the Eurosystem monetary operations. Section IV describes the data used for the analysis and provides summary statistics on those. Section V lays out the empirical analysis and its results. and Section VI concludes. The Appendix contains a description of trading in GC Pooling.

3.2 Hypotheses development

The basis for the following analysis is the emergence of allocational inefficiencies in the interbank market. Frictions can lead to allocational inefficiencies by inhibiting the flow of liquidity to banks, who need it the most. Institutional factors can also be a constraint for an efficient liquidity allocation, as they influence banks' preferences for interbank market exposures. The empirical evidence on regularities in the interbank market and the theory on frictions provide the basis for the following five hypotheses. They predict how and which regularities and frictions (i.e. short squeezing, credit risk and uncertainty about a bank's risk, link to other financial markets) affect volumes in the interbank market and the standing facilities. Therefore, if liquidity was allocated perfectly in the interbank market, the use of the standing facilities would always be close to zero, and interbank market volumes would not react to calendar day effects or frictions. The hypotheses mainly relate to the period before the policy break in the ECB/ Eurosystem monetary policy stance, the switch to full allotment. Full allotment shifts the allocation of liquidity completely to the Eurosystem, which is captured in the last hypothesis.

Interbank market rates and market activity are affected by the institutional framework and balance sheet reporting by banks. Evidence for the impact of the institutional framework on the Eonia rate is found by Nautz and Offermanns (2008), which often jumps at the end of the maintenance period.[6] That is a sign for strong imbalances at the end of the maintenance period. This will lead most likely to more volume in the interbank market as well as at the standing facilities, since banks must ensure to fulfill their reserve requirements. This means that they trade more for liquidity. At the same time banks demand more from the Eurosystem as it might be more difficult to find a cash lender, since all banks must first be certain that they are able to meet their reserve requirements themselves, before they lend money. Moreover, balance sheet reporting days create suboptimal behavior in the interbank market for liquidity. Banks want to polish their balance sheets on reporting days and lower their interbank market activity. This restricts optimal liquidity allocation in the market, forcing banks to access the standing facilities more often on these days. Munyan (2015) indeed shows that end-of-quarter and end-of-year effects have a significant negative impact on repo market activity in the US.

[6]The Eurosystem institutional setting is explained in detail in Section 3.3.

Hypothesis 1. *Trades in the interbank market as well as volumes at the Eurosystem standing facilities increase at the end of the maintenance period and decrease at the end of reporting cycles.*

The idea of squeezing is advanced by Nyborg and Strebulaev (2004) who show that the strategic behavior of short and long banks in multi-unit auctions is the result of their interactions in the secondary market for liquidity, which in turn impacts this market. Banks who are in need of liquidity submit higher bids in the auction, since they might have to pay elevated prices in the secondary market set by the bank long in liquidity exercising its market power. This incentivizes long banks to also bid more aggressively to implement a squeeze thereafter, which will be easier the more liquidity the short bank is lacking. Higher bidding aggressiveness can thus be linked to a higher potential and a higher probability for a squeeze. The potential for a squeeze may lead to unexpected allocations (some banks get more than expected, others get less), leading to a higher use of the standing facilities (Bindseil, Nyborg, and Strebulaev, 2009). Because a large potential for a short squeeze is associated with large imbalances of reserves among banks going into refinancing operations, we might also expect to see more trading in the after market. This is because imbalances may persist due to the discriminatory format of the auctions as shown by Nyborg and Strebulaev (2004).

Hypothesis 2. *The potential of short squeezing leads to an increase in the use of the standing facilities and in interbank volumes after the auction.*

Empirical evidence for short squeezing in the interbank market is provided by Bindseil, Nyborg, and Strebulaev (2009) and Fecht, Nyborg, and Rocholl (2011) by using Eurosystem auction bidding data. I complement their results by looking at traded volumes in the interbank market.

[**insert Figure 3.1 about here**]

The friction perceived to be predominant in the interbank market is credit risk, as modeled by Heider, Hoerova, and Holthausen (2015) for the unsecured market.[7] Following a similar argument as Akerlof (1970), the equilibrium in the interbank market depends on the average level of credit risk in the market as well as the dispersion of banks around this level. Every single bank's credit risk is private knowledge. In the case that the level of credit risk is low, all banks participate in the market. If credit risk is high and dispersion

[7]Credit risk has always been an integral component of the interbank market, as one can observe from the one-week interbank interest rate spread, which is defined as the difference between the unsecured rate, Euribor, and the OIS rate, Eonia swap rate. On average the Euribor was 2.71 basis points (bps) above the Eonia swap rate in the years before the crisis (see Figure 3.1).

among banks is low (zero in the extreme case), a high interest rate will be charged to all banks. If credit risk is high *and* dispersion is high, good banks will leave the interbank market as they find better funding opportunities. If credit risk is so high, that it cannot be compensated by the interest rate, the interbank market will stop working completely, or rather there will be severe credit rationing. Better information can mitigate the adverse selection problem. The easier it is to single out good banks, the better one can differentiate in the unsecured interbank market. Good banks receive a lower interest rate, whereas bad banks must pay a high interest rate and/or are credit rationed.

The adverse selection argument only refers to the unsecured interbank market. In the repo market the problem should be less severe, because loans are secured against collateral. Especially repo trading via a CCP provides protection, as trading is anonymous and the CCP becomes the counterparty to each trade. If banks refrain from trading in the unsecured market, they will likely switch to the repo market. If credit risk is so high that it impairs trading in both markets, banks will mainly use the standing facilities for managing their liquidity position.

Hypothesis 3. *When the average level of credit risk is elevated, trades will decrease in the unsecured and increase in the secured market. When credit risk is very high, less trades will occur in both the unsecured and secured market and there is a higher use of the standing facilities. A high observable dispersion in credit risk leads to market segmentation: it lowers trades in the unsecured market and raises trades in the secured market.*

The expected effects of credit risk and observable dispersion are similar, but the interpretation of both effects is different. Credit risk leads to adverse selection in the interbank market, so that the good banks leave. Instead, if there is high observable dispersion of credit risk among banks, it might be easier to identify and shut out bad banks, as in this case their individual distributions of credit risk are less likely to overlap.

The interbank market is not isolated, but linked to other financial markets. Nyborg and Östberg (2014) show that tensions in the interbank market lead to increasing traded volume of highly liquid stocks. In the same vein, liquidity conditions in other security markets may spill over to the interbank market. Brunnermeier and Pedersen (2009) show in their model that market and funding liquidity is linked. Assume that Bank A provides funding liquidity to a speculator in stocks by means of a collateralized loan, e.g. a repo or stock lending transaction. Bank A manages its own liquidity position in the interbank market, and adjusts margins based on its expectations of future prices and volatility. If expected stock market volatility goes up, Bank A raises margins, as well as all other banks from which the speculator receives funding. He might find it now very difficult to fulfill all margin requirements. Knowing that Bank A has a close relationship to that speculator, it is now perceived as riskier in the interbank market. Thus, it might have to pay a premium and/or is credit rationed. In order to avoid that Bank A turns to the repo market, ideally with anonymous trading, or to the Eurosystem standing facilities.

Hypothesis 4. *Higher stock market volatility leads to a higher use of the secured interbank market as well as the standing facilities and a decrease in the unsecured volumes.*

Frictions only impact the interbank market, as long as this is the main platform to reallocate liquidity. This role changes after the collapse of Lehman Brothers, when the Eurosystem changes the monetary policy stance, switching to full allotment. The Eurosystem becomes the main supplier of liquidity. Thus, the case of very high credit risk in Hypothesis 3 is actively counteracted by the Eurosystem. If the full allotment policy works, there should be no detectable impact of frictions in volumes.

Hypothesis 5. *After the switch to full allotment, frictions do not impact the market for liquidity.*

With the Eurosystem being the main provider of liquidity, its allocation foregoes market efficiency. However, this ensures that the liquidity supply to some banks does not dry up, which can be caused by frictions. As I will analyze in Section 3.5 frictions may inhibit a smooth liquidity allocation in the interbank market. First, the institutional details of the Eurosystem and the interbank market are discussed in the next section.

3.3 Institutional background

This section provides an overview of the structure of the interbank market, the weekly liquidity operations by the Eurosystem since March 2004, and the data that I will use. This will form the basis for the empirical analysis in Section 3.5.

3.3.1 The interbank market and the Eurosystem Open Market Operations

The interbank market can be divided into the unsecured and secured market. Transactions in the secured market are called repurchase agreements (repo). The cash receiver in a repo transaction sells securities to the cash provider and promises to buy them back after an agreed term at a fixed price plus interest (repo rate). The unsecured market has the advantage of requiring little infrastructure and is built on trust between banks. The repo market, in which loans are backed by securities, is considered to be safer. There are different tenors for loans: overnight, tomorrow/next, one week and longer maturities. The Eonia market is the European unsecured overnight market, whose volumes are part of the analysis. The unsecured overnight interest rate, the Eonia, is calculated as the daily average weighted rate of the overnight transactions of 43 panel banks who report their total trade volume and their average rate to the ECB. The average amount traded in the Eonia market in June 2014 amounts to EUR 27 billion.

One secured market, which I will use as counterpart to Eonia, is GC Pooling. In General Collateral (GC) repo the main motive is cash funding, so that the security exchanged serves as collateral. GC denotes the fact that the securities in a repo trade have to meet certain criteria and the cash taker can choose, which securities he wants to use as collateral. The total European repo market (see Figure 3.1) amounts to ca. EUR 5,500 billion in December 2013 (about twice the size of France's GDP).

GC Pooling, a market operated by Eurex Repo, allows anonymous electronic repo trading in standardized GC baskets. In this paper, I analyze trading in the ECB basket, which is the first GC Pooling basket that Eurex Repo introduced in 2005. This basket entails about 7,500 securities, of which 2,500 are issued by central banks, governments, and supranationals, and roughly 5,000 securities by credit institutions and agency credit institutions. The lowest possible rating is A-/A3. Any counterparty risk is eliminated in GC Pooling, because all trades are cleared by the CCP Eurex Clearing. In June 2014, about EUR 14 billion were traded on a daily basis in the GC Pooling overnight segment. The total daily average outstanding volume in GC Pooling is EUR 181 billion (including all maturities).

The interbank market is directly influenced by the Eurosystem Open Market Operations (OMO), which constitutes the primary market for liquidity, whereas the interbank market is the secondary market (Bindseil, Nyborg, and Strebulaev, 2009). The ECB follows a liquidity neutral policy (Nyborg, Bindseil, and Strebulaev, 2002), i.e. the Eurosystem distributes as much credit as banks need to fulfill their reserve requirements during the maintenance period, which are set by the Eurosystem.[8] The OMOs contain Main Refinancing Operations (MROs) and Long-Term Refinancing Operations (LTRO). MROs have a short maturity, whereas LTROs provide financing for three months. Since March 10, 2004, the Eurosystem carries out weekly MROs, in which it distributes loans to banks with a maturity of one week. The last MRO with a term of two weeks matures on March 17, 2004. Until October 08, 2008 it uses variable tender auctions, which are executed as discriminatory auctions. In the first stage of the crisis, it applies a policy of frontloading, which allows banks to obtain sufficient liquidity early in the maintenance period.[9] As a result of the collapse of Lehman Brothers on September 15, 2008 and its

[8]The fulfillment of reserve requirements forces banks to deposit liquidity on their current account at the Eurosystem. This amount of liquidity has to be on average equal to their level of reserve requirements. This system is in place, so that banks need to participate in the Eurosystem OMOs (European Central Bank, 2002).

[9]Jean-Charles Trichet explains the policy of frontloading in his speech delivered at the 'European Banker of the Year 2007' award ceremony on September 30, 2008.

disruptive impact on financial markets, the Eurosystem adopts a full allotment policy, in which it satisfies the total liquidity demand by banks, i.e. they hand out as many loans as demanded against collateral at a fixed interest rate. In addition, the Eurosystem injects credit using LTROs with a maturity of one year. The first one-year LTRO is settled on June 25, 2009 and matures on July 01, 2010 with a volume of EUR 442 billion. In December 2011 the first three-year LTRO is implemented.

The procedure for the MRO auctions is as follows: one day before the auction, the ECB announces the specific terms of the auction including the benchmark allotment, i.e. the amount they intend to allocate to banks during the auction. Banks have to submit their bids until 9:30am. The results of the auction are announced the same day at 11:15am. Credits are handed out against eligible collateral and are settled one day after the auction.

On average 322 banks take part in the MRO auctions in the time period analyzed. The maintenance period, during which banks have to meet their reserve requirements, lasts about one month and usually ends on a Tuesday. Occasionally, it may also end on a Monday or Wednesday. The Minimum Bid Rate (MBR) for those auctions is determined by the ECB and is framed by the rates of the standing facilities. The standing facilities can be used by banks to deposit or obtain liquidity on an overnight basis, the last liquidity resort for banks. Usually banks avoid using these standing facilities, as the interest rates in the interbank market are more beneficial for borrowers and lenders. From April 09, 1999 until May 12, 2009 the rate on the lending facility is 100 bps higher than the MBR and the rate on the deposit facility is 100 bps lower.[10] The Eurosystem cannot perfectly predict banks' liquidity needs. At the end of the maintenance period it either allocates too little or too much liquidity, which is the main driver of the use of the standing facilities in this week. Any excess or deficit liquidity is also reflected in the interbank overnight interest rate, which is expected to be close or equal to the MBR in the auction. On average the Eonia exceeds the MBR by only six bps from March 17, 2004 to June 30, 2007, but at the end of the maintenance period deviations are often more sizable as can be seen by the spikes in Figure 3.6 (also see Chapter 1 for a detailed analysis of Eonia spikes).

3.4 Data and descriptive statistics

In this section I describe the main variables of the analysis and provide summary statistics. The discussion will highlight some developments that take place in the interbank market before and during the financial crisis.

For analyzing the question of calendar day patterns and the sensitivity of the interbank market to frictions, I use two different data sources, data published on the ECB webpage

[10]The band around the MBR is then lowered to 75 bps.

and Bloomberg. The sample spans the period from March 17, 2004 to November 30, 2011, one month before the Eurosystem implements the first three-year LTRO. The liquidity injection by this LTRO leads to a sizeable decrease of interbank volumes (Figure 3.3), rendering the interbank market dispensable.[11] The analysis, therefore focuses on the period before. There are three subperiods that are of interest. The first period ranges from March 17, 2004 until the end of June 2007, which is before the crisis. The second period starts August 09, 2007 and runs until the week before the collapse of Lehman Brothers (until September 12, 2008).[12] The last period starts with the introduction of full allotment by the Eurosystem on October 09, 2008 and ends November 30, 2011. The endogenous variables consist of interbank market volume data and the use of the Eurosystem standing facilities. The exogenous variables capture calendar day effects and potential sources of frictions. First endogenous variables are described, and their descriptive statistics are discussed. Then I move to the presentation of the exogenous variables.

[**insert Figure 3.3 about here**]

Endogenous variables. The dataset is composed of daily volumes at the standing facilities (*Standing fac., Deposit fac., Lending fac.*), which was retrieved from data published by the ECB on liquidity conditions in the Euro area. In addition, I retrieved data on daily volumes and interest rates on the unsecured overnight market Eonia and the secured CCP market GC Pooling from Bloomberg (*Eonia, GC Pooling*), which obtains GC Pooling data from Eurex Repo. The Eonia data begins in 2004, whereas the GC Pooling data is only available since June 01, 2007. The Eonia volume is analyzed for all periods and GC Pooling volumes for the crisis periods[13].

Tables 3.2 and 3.3 provide summary statistics on those volumes for each period: pre-crisis, first stage of the crisis and full allotment (in Panel A, B, and C). Volume statistics are complemented by statistics on the benchmark allotment (retrieved from the ECB), which is the liquidity neutral amount the Eurosystem intends to allocate in the MRO. It is announced one day ahead and the Eurosystem may deviate from this amount in the auction, if it updates its estimates of this amount. The statistics on the deviation are also displayed in this table as well as the friction measures, which are discussed subsequently.

[**insert Tables 3.2 and 3.3 about here**]

[11] In the two three-year LTROs settled on December 22, 2011 and March 01, 2012 a total of EUR 1 trillion in credits are distributed to banks, which dampens activity in the interbank market to a very low level.

[12] On August 07, 2007 BNP Paribas closes two funds related to subprime mortgages, so that markets starts to realize that there is a severe problem. The difference between the one-week Euribor and the one-week Eonia Swap spread increases from 1 basis point to 15 bps on August 09, 2007.

[13] Since GC Pooling was introduced in 2005, its volume has reached a considerable size only in 2007.

In the pre-crisis period (Table 3.2, Panel A), the Eurosystem standing facilities are used only to a limited extent. The daily volume average is EUR 359 million. In comparison, EUR 39,000 million are traded in the unsecured overnight market on a daily basis. The overnight GC Pooling market is still small, about 10% of the Eonia market with an average volume of EUR 3,300 million. The average deviation from the benchmark allotment in the MROs is EUR 760 million, which confirms that the Eurosystem follows a liquidity neutral policy (Nyborg, Bindseil, and Strebulaev, 2002).

During the first stage of the crisis (Table 3.3, Panel B), one can observe changes in the analyzed volumes. The use of the standing facilities increases to about EUR 739 million per day. This is driven by an increased use of the deposit facility, by about EUR 370 million, whereas the average use of the lending facility only increases by EUR 11 million. In the overnight interbank market, volumes increase as well, in the Eonia market by about 25% to EUR 52,000 million and in GC Pooling by more than 100% to EUR 7,000 million, as it is still a growing market. The higher use of the deposit facility points reflects liquidity hoarding and volumes that are not reallocated in the interbank market. Despite this, there are also higher volumes in the Eonia and GC Pooling market, both overnight. This may be explained by a shift from long to shorter maturities, as term markets become more illiquid (European Central Bank 2008). Another important point to note is that the average deviation from the benchmark allotment increases from EUR 1,000 million to EUR 25,100 million in this period, with a maximum of EUR 217,000 million. This is allegedly the result of the Eurosystem's new policy of frontloading, so that banks can fulfill their reserve requirements early. The Eonia – MBR spread (see Figure 3.6) stays positive, which suggests that the Eurosystem does not completely abandon its liquidity neutral policy.

[**insert Figure 3.4 about here**]

After the collapse of Lehman, when full allotment is introduced (Table 3.3 Panel C), tensions in the interbank market become severe. Volumes at the standing facilities shoot up to an average of EUR 119,000 million (Figure 3.4), which is the result of an excessive use of the deposit facility (mean of EUR 117,110 million). The use of the lending facility also rises, but to a smaller extent with an average amount of EUR 1,401 million. Volumes in the unsecured interbank market decline to an average of EUR 35,490 million, whereas volumes in GC Pooling increase to EUR 9,564 million. The large volume at the deposit facility is the consequence of the unlimited liquidity supply by the Eurosystem that is apparently used as substitute for interbank market liquidity. The total outstanding liquidity from Eurosystem monetary policy operations is higher than before, EUR 633,000 million. In combination with an increased use of the lending facility it points to strong problems in the interbank market. It seems that several banks have completely lost access and thus resort to Eurosystem liquidity and its standing facilities. GC Pooling market volume sees an increase due to its safe trading mechanism, whereas the Eonia market loses volume, as unsecured loans are considered too risky to hand out. So it is vital to analyze the development of the frictions in the interbank market.

Exogenous variables. They are composed of measures for frictions and calendar day effects. Calendar day effects (Hypothesis 1) are captured by dummy variables. I control for daily (*Weekday*), end-of-the-quarter(*DumQtr*) and last week of the maintenance period (*Endres*) effects. Information on the maintenance period and dates of the Open Market Operations were retrieved from the ECB website.[14]

The first friction measure is bidding aggressiveness (*Bidag*), the variable for short squeezing (Hypothesis 2), whose data was collected from the ECB website, in particular the dates of the auctions, the weighted average winning bid rate and the stop-out rate of the auction and liquidity allotted in MROs and LTROs. Bidding aggressiveness (*Bidag*) is measured by the spread of the weighted average bid rate – one-week Eonia Swap on the Eonia before the auction (8:30am). The Eonia Swap is the main alternative to participating in the MRO. Banks may short the Eonia swap and invest in the interbank market overnight at the Eonia rate (Bindseil, Nyborg, and Strebulaev, 2009). The Eonia Swap rate at 8:30am is taken from Carl Kliem Interbank & Securities Broker and was provided by the ECB. The fact that banks choose to bid at higher rates in the Eurosystem auction, given the current interbank market rate, indicates their need for liquidity and their fear to be squeezed later. A higher value of *Bidag* is linked to higher funding risk. Due to the weekly rhythm of the MROs, *Bidag* is available at a weekly frequency.

With the introduction of full allotment the variable of bidding aggressiveness cannot be used any longer, as the Eurosystem provides loans at a fixed rate satisfying banks' total liquidity demand. The possibility of squeezing due to liquidity shortage from the Eurosystem thus diminishes. Instead, the unlimited liquidity supply by the Eurosystem leads to the opposite effect, excess outstanding liquidity, which needs to be controlled for. The amount of liquidity in the system in this period is captured by the sum of the outstanding MRO and LTRO amount (*Liq*).

To capture credit risk (Hypothesis 3), CDS data from Eonia panel banks and from GC Pooling banks, which participate in December 2009, is used.[15] The data of the end-of-day mid points of the 5-year CDS spreads was retrieved from Bloomberg. If the CDS of a bank is not traded on one day, the value of the last day is used. Banks that were nationalized or encountered severe problems during the financial crisis (and thus had to be saved by other banks and/or the government) were excluded from the panel as well as banks that do not have CDS contracts that can be traded. This leaves 35 banks in the Eonia panel

[14] The link is http://www.ecb.europa.eu/events/calendar/reserve/html/index.en.html.

[15] The names can be found in the Table 3.1.

out of 43 and 17 out of 22 in the GC Pooling panel. 12 banks are represented in both panels. The CDS spreads of all banks are averaged each day to determine the mean CDS spread (*CDS*). The average CDS spread is calculated for GC Pooling, Eonia separately and their combined panel for the analysis of the use of the standing facilities. In order to measure the dispersion of credit risk, the same raw data is used as for the measure of credit risk.

Uncertainty about the credit risk of a single bank (Hypothesis 3) is measured by the coefficient of variation, i.e. the standard deviation of banks' CDS spreads divided by the average level of CDS, where the latter is calculated as a moving-average of the previous ten days (*CoeffVar*). This measure is unitless and captures the dispersion of CDS spreads each day given the aggregate level of credit risk. The higher the *CoeffVar* is, the easier it is to distinguish safe and risky banks. The sign of the coefficient of *CoeffVar* will indicate, if more precise information/ lower uncertainty about a single bank's credit risk increases or lowers volumes in the unsecured interbank market.

The last friction measure, the connection to other financial markets (Hypothesis 4), is captured by the VSTOXX, which measures expected volatility in the stock market (*VSTOXX*). It is calculated from EURO STOXX 50 option prices. A higher VSTOXX is expected to have a negative impact on the unsecured market and a positive impact on the other analyzed volumes.

Summary statistics on all friction measures are reported in Tables 3.2 and 3.3. In the pre-crisis period, Panel A, frictions are at a low level. Bidding aggressiveness is on average -1.13 bps, indicating that banks bid below the interbank market rate in the auction. The maximum average bidding aggressiveness, however, is 10 bps above the interbank market rate. The CDS spreads of the total panel of banks and the individual market panels (as explained above) vary on average from 12.68 bps to 14.40 bps, with GC Pooling having the riskiest panel. The coefficient of variation shows a different pattern, its highest average value is reached for the Eonia panel with 0.384. The VSTOXX displays low volatility with a mean of 16.4 index points. In this period there are no signs for disruptions of the interbank market as one expects. There is no direct sign for strong short squeezing, as the bidding aggressiveness has on average a negative value.

In the first stage of the crisis, Table 3.3 Panel B, all frictions measures rise. The bidding aggressiveness of banks increases as compared to the previous period. The mean is higher by 17 bps and the value is always positive, as the minimum is 0 basis points, indicating that the lower bound is now given by the interbank market interest rate. The average CDS spread of the total panel rises in this period to 68 bps. In addition, the mean of the coefficient of variation as well as the VSTOXX are higher with values of 0.43 and 24.40 index points. So the interbank market experiences tensions. Interbank loans are on average riskier now, as the banks' average credit risk is higher. This may lead to less interbank lending. Eonia and GC Pooling volumes are higher in this period, but they most likely profit from a shift to shorter maturities in transactions, which is triggered by these tensions. There is potentially market segmentation, as indicated by a higher coefficient of variation. Some banks have problems acquiring funds, thus also bidding more aggressively in the auctions (Cassola, Hortacsu, and Kastl, 2013). That is, funding risk has risen for many banks. Banks respond by keeping the liquidity obtained in the MRO in the deposit facility instead of lending it to banks short in liquidity. Overall, this period is marked by strong frictions inhibiting trading in the interbank market.

In period of full allotment, Table 3.3 Panel C, all friction measures are even higher than in the previous period, providing evidence that the Lehman collapse constitutes a severe disruption to the interbank market. The average CDS spread of the whole panel is 176 bps and the coefficient of variation rises to 0.721, possibly leading to higher market segmentation. The average VSTOXX is 32.2 index points. The large liquidity accumulation at the Eurosystem deposit facility, higher use of the lending facility, low volumes in the Eonia market and high level of frictions point towards a partly dysfunctional interbank market. This is supported by higher volume in GC Pooling, where banks can obtain credit regardless of differences in their credit risk. Now I turn to the empirical analysis of calendar day effects and frictions.

3.5 Empirical Analysis

This section shows the results for the study of frictions and interbank market volumes. Before evaluating the impact of frictions in a regression model, I first analyze calendar day effects (Hypothesis 1) to better understand, how the institutional framework affects (optimal) liquidity allocation in the interbank market. This gives way to the analysis of the impact of frictions on volumes.

3.5.1 Calendar day effects

In this first part of the empirical analysis I study the calendar day effects of the standing facilities, the Eonia and the GC Pooling market. This sheds light on the first hypothesis. In the ideal case of a fully efficient and balanced interbank market there are no seasonal effects in the use of the standing facilities and traded volumes. In Figure 3.3 one can recognize recurrent spikes in the volumes of Eonia, GC Pooling and the standing facilities indicative of patterns. I run daily time-series regressions for each volume on a set of dummy variables capturing calendar days. The baseline regression, estimated by OLS, takes the following form (standard errors are corrected by Newey-West's method with lags being determined by the integer closest to the fourth root of the number of observations

(Greene, 2008). Volumes are in logs.

$$\mathrm{y}_t = \alpha_0 + \alpha_1 \mathrm{Endres}_t + \alpha_2 \mathrm{DumQtr}_t + \sum_{k=3}^{6} \alpha_k \mathrm{Weekday}_{k,t} + \sum_{m=7}^{12} \alpha_m \mathrm{Weekday}_{k,t} * \mathrm{Endres}_t + \varepsilon_t, \quad (3.1)$$

where y_t denotes the log volume of the standing facilities, the deposit facility, the lending facility, Eonia, and GC Pooling volume. *Endres* is the last week of the maintenance period, *DumQtr* is the last day of the quarter, *Weekday* denotes the day of the week (Monday to Thursday indicated by k) and t is the time index. The last week of the maintenance period is interacted with the respective day dummies (*Weekday*Endres*). For GC Pooling an additional variable is added in the second period, 21 Dec 2007 – 31 Dec 2007, when nearly no trades take place (*Endyear*). In the last period, full allotment, a dummy variable for the one-year LTRO is added to the regression (*One-Year LTRO*). It is equal to one for the period 25 Jun 2009 - 01 Jul 2010. In this period liquidity is overly abundant, as EUR 442 billion are allotted in this LTRO.

[**insert Tables 3.4, 3.5 and 3.6 about here**]

The results are displayed in Tables 3.4, 3.5 and 3.6. The most distinct effects can be found for the last week of the maintenance period and the end of the quarter. In the pre-crisis period (Table 3.4) the last two days of the maintenance period (*Monday*Endres, Tuesday*Endres*) turn out to be significant at the 1% level for the use of the standing facilities. The use of the standing facilities is enormous on the last day of the maintenance period with a level by 1,000% higher than on a Friday outside the last week of the maintenance period. In the Eonia market the volume is larger on the last three days of the maintenance period. The relative increase is smaller, about 30%. The end of the quarter (*DumQtr*) plays a similarly important role and has a comparable size effect on the use of the standing facilities. Trading in the Eonia market decreases by 20% at the significance level of 1%. The end of the quarter effect in the Eonia market has been documented by Bindseil, Weller, and Wuertz (2003). Gropp and Heider (2010) and Teixeira, Silva, Fernandes, and Alves (2014) note that banks usually hold Tier 1 capital in excess of regulatory requirements, with the level being specific to each bank. This implies that banks want to improve their balance sheet at the end of the quarter, also called window dressing. The increase in interbank market activity at the end of the maintenance period implies that banks use it to obtain the liquidity they need for fulfilling their reserve requirements. Higher volumes at the standing facilities, however, indicate that there is supply and demand for liquidity that does not meet in the interbank market. Potential counterparties of a bank might have already traded and so banks resort to the standing facilities. This is a cause of the decentralized nature of the interbank market. On days when there is more demand for liquidity or when banks reduce interbank positions as at the end of the quarter, it is more difficult to obtain liquidity in the interbank market. There is a higher potential for stress on those days.

In the first stage of the crisis, Table 3.5, only the last day of the maintenance period matters for the use of the standing facilities (*Tuesday**Endres*), with a similar size effect as before. The Eonia market does not show any specific day patterns or rise at the end of the maintenance period. The end-of-the-quarter effect strengthens for the use of the standing facilities (except for the lending facility) and the Eonia market. In the case of GC Pooling only the end of the year 2007 (*Endyear*) is significant, when nearly no trades take place. Due to higher frictions in the interbank market (Section 3.4), the Eurosystem adjusts its liquidity distribution during the maintenance period to frontloading. Most banks seem to fulfill their reserve requirements before the end of the maintenance period. So frontloading alleviates possible liquidity constraints at the end of the maintenance period, which proves to be effective. The strengthening of the end-of-quarter effect is in line with Teixeira, Silva, Fernandes, and Alves (2014)'s findings who show that Tier 1 capital ratios are even higher in this period in Europe, which is due to the various equity injection schemes in many countries. In this period banks have an incentive to appear strong (as they also face many write-offs), thus window dressing is a main driver of the end-of-quarter effect.

The full allotment policy of the Eurosystem modifies the trading behavior of banks in the interbank market, Table 3.6. The last day of the maintenance period leads to negative spikes for the use of the standing facilities (except for the lending facility) and in Eonia volumes (lower by 90% and 9%). GC Pooling volumes show no reaction. The end of the quarter is not important for the use of the standing facilities any longer, whereas volumes in the Eonia market and in the GC Pooling market still react negatively. The first one-year LTRO (*One-Year LTRO*) implemented by the Eurosystem shows a positive effect on the use of the deposit facility, negative for the lending facility and negative for Eonia and GC Pooling. The negative coefficients on the last day of the maintenance period are a result of banks shifting liquidity from the deposit facility to their current accounts to fulfill the reserve requirements. Banks focus on fulfilling their reserve requirements and do not release liquidity to the interbank market. The negative impact of the one-year LTRO on interbank volumes implies that banks continue to substitute secondary market liquidity with primary market liquidity (Bindseil, Nyborg, and Strebulaev, 2009).

The analysis of calendar day effects shows that the Eurosystem institutional framework has a strong impact on trading in the interbank market. In times of low market disturbances, there are strong seasonal effects at the end of the maintenance period. Seasonal effects due to the institutional framework change the more accommodating the Eurosystem monetary policy becomes. They imply, especially seasonality in the volumes at the standing facilities (before the crisis), that liquidity allocation in the interbank market is not perfectly efficient, when institutional factors become binding. At the end of the reporting period banks actively manage their balance sheet. This lowers activity in the interbank market, showing that in terms of reporting it is less preferable than the standing facilities, which are usually more expensive to use than the interbank market.

The role of the interbank market changes completely, when the Eurosystem switches to full allotment. This leads to different patters in interbank market trading, as seen in the regression results. It is not used anymore as the main tool for fulfilling reserve requirements, but for obtaining liquidity on an ad-hoc basis. The Eurosystem is now the main liquidity provider. I will examine the frictions and volumes in two time frames, before the collapse of Lehman and full allotment (Mar 17, 2004 –Sep 14, 2008) and after the start of full allotment (Oct 09, 2008 – Nov 30, 2011). The first period is used to test Hypotheses 2-4 as outlined in Section 3.2, whereas the second period tests if the impact of frictions is eliminated after the change in the Eurosystem monetary policy, Hypothesis 5. Given that frictions impact the use of the standing facilities and lower trading in the interbank market, this points towards allocational inefficiencies.

3.5.2 Frictions

In this subsection I analyze the impact of frictions on interbank volumes and the use of the standing facilities, i. e. I test the previously stated Hypotheses 2-4 (Section 3.2). The following time-series regression is run

$$\begin{aligned} \mathrm{y}_t = \beta_0 &+ \beta_1 \mathrm{Bidag}_{t-1} + \beta_2 \Delta\mathrm{CDS}_{t-1} + \beta_3 \Delta\mathrm{CoeffVar}_{t-1} + \beta_4 \mathrm{VSTOXX}_{t-1} \\ &+ \beta_4 \mathrm{Endres}_t + \beta_5 \mathrm{DumQtr}_t + \sum_{j=1}^{n} \gamma_j y_{t-j} + \varepsilon_t, \end{aligned} \tag{3.2}$$

where y_t represents the interbank volume/ use of the standing facilities, *Bidag* measures bidding aggressiveness, *CDS* is credit risk, *CoeffVar* the information about the distribution of credit risk and *VSTOXX* the expected volatility in the stock market. *Endres* is a dummy variable for the last week of the maintenance period and *DumQtr* is the week containing the last day of the quarter, y_{t-j} are autoregressive terms with t denoting the time index and j the lag. In the second period analyzed, the period of full allotment, *Bidag* is dropped and ΔLiq is added, which measures the change in total liquidity outstanding by the Eurosystem. Moreover, the dummy variable *One-Year LTRO* is added that is equal to one for the period June 25, 2009 – July 01, 2010.

In order to match the weekly frequency of the MROs, I calculate weekly averages for all endogenous and exogenous variables starting from the settlement day of the auction to the next auction day, whereas bidding aggressiveness based on weekly data is calculated on the day of the auction. The regressions are run separately for each volume (in logs), i. e. the use of the standing facilities, deposit, and lending facility, volumes in the Eonia and GC Pooling market. The explanatory variables are lagged by one week to avoid simultaneity between the dependent and independent variables. Thus, I measure the subsequent development of volumes after e.g. a change in credit risk.

Autoregressive terms (AR model) are included in each regression. If the interbank market only changes as a result to new shocks, which I want to capture, then autoregressive terms are vital for the test. The number of lags is determined by the Hannan-Quinn criterion. This criterion is strongly consistent and balances out too many and too few lags (Lütkepohl, 2007). The maximum lag length is five weeks, because the maximum length of the maintenance period in my sample is six weeks and the most relevant information is contained in the current maintenance period. At the same time autocorrelation is controlled for.

Volumes, bidding aggressiveness and VSTOXX are stationary, whereas credit risk as well as dispersion are non-stationary.[16] Volumes, *Bidag* and *VSTOXX* were demeaned, while the non-stationary variables, *CDS* and *CoeffVar*, were differenced. Since both variables *CDS* and *CoeffVar* were calculated on the same data basis, the change in *CoeffVar* as well as the demeaned *VSTOXX*[17] were individually regressed on the change in *CDS* for both periods considered, to single out its effect. The first-stage regressions were run without an intercept, since it was not significant in any of those models. The residuals of the first-stage regression are then included in the estimation. The regression for measuring frictions is estimated by means of full maximum likelihood (FMLE), which includes the initial observations in the estimation. The final regression model looks the following:

$$\begin{aligned} \mathrm{y}_t = \beta_0 + \beta_1 \mathrm{Bidag}_{t-1} + \beta_2 \Delta\mathrm{CDS}_{t-1} + \beta_3 \mathrm{Res}_{(\Delta\mathrm{CoeffVar} \mid \Delta\mathrm{CDS}),\mathrm{t-1}} \\ + \beta_4 \mathrm{Res}_{(\mathrm{VSTOXX} \mid \Delta\mathrm{CDS}),\mathrm{t-1}} + \beta_4 \mathrm{Endres}_t + \beta_5 \mathrm{DumQtr}_t + \sum_{j=1}^{n} \gamma_j y_{t-j} + \varepsilon_t. \end{aligned} \tag{3.3}$$

Results for the Period before Lehman

Table 3.8 shows the results of the regressions in the period before the collapse of Lehman Brothers. The first autoregressive term, y_{t-1}, is significant for all volumes except for the use of the lending facility. The highest persistence can be seen in the Eonia volume with a coefficient of 0.67. Bidding aggressiveness (*Bidag*$_t$) has a significant effect on the use of the standing facilities, and on the deposit facility itself. One basis point higher yields a higher use of the standing facilities by 3.4%, whereas the use of the deposit

[16]Dickey-Fuller tests are reported in Table 3.7 Bidding aggressiveness is stationary for the pre-crisis and first stage of the crisis separately, but not when both periods are combined. For now it is treated as stationary variable, but since there are signs for a structural break in this variable, this will be later taken into account.

[17]Since *VSTOXX* is econometrically stationary, it was not differenced, in order to preserve the characteristics of this variable. Differencing a stationary variable will render the time series of that variable non-invertible, which is undesirable for the regression (Hamilton, 1994).

facility is even higher by 4.8%, significant at the 1% level. Credit risk (ΔCDS_{t-1}) plays a role in the Eonia market and GC Pooling market, but not for the use of the standing facilities. A change in the average level of credit risk by one basis point raises the Eonia volume in the following week by 0.7% and GC Pooling volume by 1.9%. The coefficient of variation ($Res_{(\Delta CoeffVar \mid \Delta CDS),t\text{-}1}$) has a significant negative impact on volumes in the Eonia market, but not on other volumes. An increase by 0.1 points in the coefficient of variation leads to a 8.5% decrease in the Eonia volume. A rise in the expected volatility ($Res_{(VSTOXX \mid \Delta CDS),t\text{-}1}$) by one index point raises the use of the standing facilities the following week by 5.4% at the 1% significance level, which is driven by the deposit facility. It also raises the volume in GC Pooling by 4.6%.

[**insert Table 3.8 about here**]

The implications of those results for the hypotheses in Section 3.2 are mixed. The positive effect of bidding aggressiveness on the use of the standing facilities, which relates to Hypothesis 2, means that the potential of a squeeze may lead to allocational inefficiencies in the interbank market. Excess liquidity is parked at the deposit facility and is not completely reallocated in the interbank market. The Eonia–MBR spread actually seems to drop following an aggressively bid auction (Table 3.12). This will be studied in more detail in Section 3.5.3 The coefficient on credit risk for Eonia is not in line with the hypothesis that volumes in the unsecured market decrease after a change in credit risk. Given that credit risk is elevated in the period before the collapse of Lehman, its coefficient was expected to be negative. One likely explanation is the shift from long maturities to short maturities in the first stage of the crisis as observed in Section 3.4. The Eonia market, thus, serves as market with low credit risk. The result on credit risk is complemented by the result of the coefficient of variation. A higher coefficient results in a decrease of Eonia volumes, which points into the direction of market segmentation. If single banks become riskier, they are excluded from the Eonia market. However, these regressions do not show evidence that these banks turn to the standing facilities for obtaining liquidity. The standing facilities do not display higher usage after an increase in credit risk or the coefficient of variation.

The overnight GC Pooling market shows a positive reaction to credit risk, which is due to a combination of its short maturity and its safety due to the CCP. It does not react to the change in uncertainty about the riskiness of single banks. Thus, it acts as a risk buffer for the complete market as indicated by Mancini, Ranaldo, and Wrampelmeyer (2016)'s results. This is also in line with the first part of Hypothesis 3 on credit risk. The non-sensitivity of GC Pooling to the uncertainty about the risk of single banks does not accord with the second part of Hypothesis 3, as neither risky Eonia banks nor risky banks in the GC Pooling panel obtain additional liquidity on the aggregate from GC Pooling. The riskiest banks in the Eonia panel at the end of the period are Dexia, Bank of Ireland

and Caixa, who are not participants of GC Pooling. Banks that are potentially excluded from the Eonia market have to use other ways to obtain liquidity. If there are liquidity constrained banks in GC Pooling due to credit risk, this is not reflected in its overall daily trading volume.

The higher use of the deposit facility following an increase in expected stock market volatility (Hypothesis 4) indicates precautionary liquidity hoarding (Acharya and Merrouche, 2012), in case that the access to interbank market liquidity becomes more difficult. The higher volume in GC Pooling is also in line with Hypothesis 4, as eventually banks perceived as risky trade more in the anonymous repo market. Overall, frictions in the interbank change the use of the standing facilities, and volumes in the interbank market, supporting the notion that they impact the allocational efficiency of the interbank market.

Another question that arises is the timing of the effect of the variable of the uncertainty about the credit risk of a bank on the Eonia volume. Is it related to the end of the maintenance period? Or is it linked to the accumulating difficulties of banks in September 2008? In order to study these questions, I add an interaction term to the regression analysis before Lehman. The first interaction term is the product of the dummy for the last week of the maintenance period and the coefficient of variation. The second interaction term is given by the product of a dummy for the month of September and the coefficient of variation. The answer to the first question is no[18] and the answer to the second one is yes, Table 3.15. Market segmentation rises at the beginning of September, when rumors begin to spread about the funding difficulties of Lehman Brothers, which leads to increasing and diverging CDS spreads, as many financial institutions have exposures to Lehman. For GC Pooling this effect is not present. However, its volumes do rise in September. So Eonia volume is negatively affected by higher riskiness of single banks, whereas increasing tensions lead to an larger volume in GC Pooling.

Results for the Period of Full Allotment

Due to the large liquidity supply by the ECB, measures of frictions are expected to be insignificant (Hypothesis 5). Results for the period after the start of full allotment are displayed in Table 3.9. Persistence in volumes, y_{t-1}, increases for the use of the standing facilities and the interbank market. The coefficient on ΔLiq is significant for Eonia, GC Pooling volumes and the use of the standing facilities. A change in outstanding liquidity decreases volumes in Eonia and GC Pooling markets by 54% and 70% at the 1% significance level. A change in credit risk (ΔCDS_{t-1}) only affects the use of the standing facilities, especially the deposit facility, significantly. A positive change in credit risk by one basis point raises the use of the deposit facility by 0.5%. The coefficient of variation ($Res_{(\Delta CoeffVar\ |\ \Delta CDS),t\text{-}1}$) does not affect Eonia volumes in this period. It is

[18] The results are available on request.

weakly significant for GC Pooling volumes with a positive impact and not for the use of the standing facilities. Expected volatility ($Res_{(VSTOXX \mid \Delta CDS),t\text{-}1}$) positively affects the use of the lending facility.

[insert Table 3.9 about here]

After a positive change in credit risk the use of the standing facilities rises, which is driven by the deposit facility.[19] The lending facility is not affected, neither are Eonia or GC Pooling. This implies that, despite the full allotment policy, credit risk remains an important factor and leads to liquidity hoarding at the deposit facility. Increases in credit risk have no impact on the use of the lending facility, but a subsequent test (Table 3.13) demonstrates that the amount allotted to banks in MROs and LTROs rises as a result.[20] The coefficient of variation only has a weak impact in this period, not on Eonia but on GC Pooling, indicating that if some banks are known to be riskier than others then volumes tend to be higher in GC Pooling. Higher expected stock market volatility leads to a higher use of the lending facility. As Abbassi, Bräuning, Fecht, and Peydró (2014) show, interbank market access after the collapse of Lehman becomes more difficult for banks, which is amplified by strained conditions in other financial markets. Therefore, more banks are forced to use the lending facility.

The period after full allotment thus provides partial support for Hypothesis 5, which says that frictions do not impact the market for liquidity anymore. The Eonia market shows no sensitivity to frictions anymore, since the Eurosystem is now the main liquidity provider. However, the positive reaction of the use of the standing facilities and liquidity demand in MRO and LTRO auctions to credit risk is not consistent with this hypothesis. This result points towards stronger credit rationing in the interbank market, when credit risk rises further. Despite its lower significance for liquidity reallocation (due to monetary policy and/or breakdown of this market Heider, Hoerova, and Holthausen (2015), the volume in the unsecured market is still considerably high (Section 3.4)). It is allegedly used for liquidity distribution among interrelated banks, e.g. German Landesbanken.[21] Instead, the GC Pooling market can provide liquidity, if the unsecured interbank market is tight. A bank cannot be excluded from trading in GC Pooling by other participants as long as Eurex allows its access to its repo markets. GC Pooling does not show an increase in volumes after a change in credit risk, but when individual banks become riskier, which

[19] As a check that eventually other risky banks influence trading in GC Pooling and Eonia, I use as a measure of credit risk and coefficient of variation data from the panel of banks in January 2011. The results are qualitatively the same. So the banks that drive the results in this period are included in the 2009 panel.

[20] Including the other risk variables in the regression yields the same result.

[21] These are state-owned banks in Germany, who are regionally organized and concentrate on wholesale banking.

is a sign for market segmentation. So GC Pooling acts as risk buffer for single banks, but not necessarily for the whole market.

The change in liquidity policy by the Eurosystem takes volume from the interbank market and thus its role of reallocation of liquidity as evidenced. This is also in line with Mancini, Ranaldo, and Wrampelmeyer (2016). Instead of being used as a fallback option, the deposit facility takes the role of liquidity storage. Inefficiencies in the interbank market persist despite the excessive liquidity supply by the Eurosystem, indicating that the liquidity injection by the Eurosystem is necessary, as otherwise frictions would prevent many banks from obtaining liquidity in the interbank market, thus resulting in large allocational inefficiencies.

The analysis of both periods shows that the interbank market is exposed to different frictions. Eonia and GC Pooling markets seem to be safe havens in the period before Lehman, rising volumes when credit risk increases. Despite this fact, there are signs of market segmentation in the Eonia market. The standing facilities experience liquidity hoarding, which explodes in the period of full allotment, when liquidity supply by the Eurosystem is unlimited. This takes away volume from Eonia and GC Pooling markets. The latter market is still a reliable liquidity source in the period of full allotment.

3.5.3 Squeezing and Risk factors

The mechanics of squeezing

Unlike the other frictions analyzed, squeezing does not result from inherent uncertainty in the banking sector, but stems from the strategic interplay between banks. Thus, it deserves a closer look. It mainly occurs in the liquidity neutral policy period and so the focus in this section is on the period before Lehman (Nyborg, Bindseil, and Strebulaev, 2002). Recalling Hypothesis 2: *the potential of short squeezing leads to an increase in the use of the standing facilities and in interbank volumes after the auction.* The question is if the Eurosystem reacts to the potential of short squeezing by injecting more liquidity into the banking sector, if banks bid more aggressively.

The first step is to divide the sample into two subperiods (pre-crisis and first stage of the crisis). Results are displayed in Tables 3.10 and 3.11. Bidding aggressiveness (*Bidag*) is not significant in any of those. The result is thus driven by the difference in the level of bidding aggressiveness in both periods. Fecht, Nyborg, and Rocholl (2011) find evidence that the liquidity needs of banks leads to higher bidding aggressiveness in the auction. The more dispersed liquidity balances are before the auction, the more aggressively banks bid. Cassola, Hortacsu, and Kastl (2013) note that banks increase their bidding aggressiveness during the crisis. Two-thirds of this increase are driven by a higher willingness to pay for liquidity, whereas for the other third this is a strategic response. The Eurosystem acts more accommodatively in the second period (first stage of the crisis), thus volumes at the deposit facility are higher.

In order to understand the relationship between bidding aggressiveness, the Eurosystem liquidity provision, and the interbank market, I perform further tests, as documented in Table 3.14. My focus is on bidding aggressiveness and the deviation of the allotted amount in the auction to the pre-announced benchmark allotment. The question is if the Eurosystem deviates by more from this announced amount, if they observe a high bidding aggressiveness. That would lower the probability of a short squeeze. In order to exclude other factors, the period analyzed is the period before the start of the crisis. Variables are defined as in the previous sections.

[**insert Table 3.14 about here**]

The first column of Table 3.14 shows that bidding aggressiveness is positively related to the end of the maintenance period. The deviation of the allotted amount to the benchmark allotment is higher when the bidding aggressiveness in an auction is high. The relationship is supposedly not perfect, i.e. the Eurosystem injects more into the interbank market based on their updated beliefs of what is needed in the banking sector. In the last auction of the maintenance period the deviation is not significantly higher, since the Eurosystem accounts for the end of the maintenance period in their estimation and rather distributes too much liquidity than too little. This is supported by the fact that the spread Eonia–MBR often spikes downwards at the end of the maintenance period.[22] For banks it is probably easier to deal with excess liquidity than too little liquidity at the end of the maintenance perio.

The volume at the deposit facility does not increase when the deviation is higher, but the traded volume in the Eonia market does. Since I want to focus on the spread Eonia–MBR that relates to bidding aggressiveness, the last week of the maintenance period was removed for the analysis of squeezing. The Eonia-MBR spread reacts negatively to an increase in bidding aggressiveness and positively to the deviation amount. So the part of the deviation that correlates with bidding aggressiveness leads to an easing of liquidity conditions in the interbank market, driving down the spread. The deviation that is not related to bidding aggressiveness has the opposite effect. The Eurosystem has revised its estimates of liquidity needs, but seems to underestimate those liquidity needs, since the spread is subsequently higher, as well as trading in the interbank market. Nevertheless, these results imply that squeezing does not materialize in the interbank market after an aggressively bid auction. The Eurosystem acts accommodatively. Thus, the occurrences of allocational inefficiencies due to short squeezing after an aggressively bid auction are reduced by the accommodative reaction by the Eurosystem.

[22] In 23 out of 39 maintenance periods the Eonia–MBR spread turns negative in the last week of the maintenance period (see Figure 3.6).

The relationship of the different risk factors

This part focuses on the risk friction measures. The measures CDS, CoeffVar and VSTOXX are highly correlated. In the main test, they are conditioned on CDS, which measures credit risk. Here, I change the order of conditioning. I now condition on the variable CoeffVar. Results are shown in Tables 3.16 (period before Lehman) and 3.17 (period of full allotment). All results are the same in the period before Lehman, except for two changes. The effect of $\Delta CoeffVar$ on the Eonia volume and the effect of $(Res_{(\Delta CDS \mid \Delta CoeffVar),t\text{-}1})$ on GC Pooling volumes are insignificant, but they still carry the same sign. In the period of full allotment the coefficient of variation becomes significant in the regression of the deposit facility and GC Pooling. It implies that indeed ΔCDS and $\Delta CoeffVar$ capture a similar variation, which tends to strengthen the impact of one variable on the respective volume.

When all variables are regressed on VSTOXX instead, results in the period before Lehman are qualitatively the same except for the insignificance of the coefficient of credit risk in the GC Pooling regression.[23] In the period of full allotment it also subsumes the effect of credit risk on the standing facilities without strengthening its own impact. There is a common component of credit risk with the coefficient of variation and volatility.

3.6 Conclusion

In this paper I provide evidence that in normal times liquidity reallocation in the interbank market is not always perfectly efficient (measured by the use of standing facilities), which is impaired further by frictions. Credit risk is the central friction. The more severe it is, the worse conditions are in the interbank market. The switch to full allotment replaces the interbank market by primary market liquidity provision. However, the liquidity uptake and storage at the Eurosystem is still a function of credit risk, implying that tensions in the interbank market are still present.

First, I find that seasonal effects arise from the Eurosystem institutional framework and reporting cycles. The end of the maintenance period sees higher volumes in the interbank market and also a higher use of the standing facilities. The latter indicates that there is excess demand and supply of liquidity that is not cleared in the interbank market. At the end of the quarter window dressing plays a significant role. Banks reduce risky interbank loans and prefer to store at or borrow liquidity from the safe standing facilities. In the first stage of the crisis, calendar day effects become less important in the interbank market, as the ECB starts to loosen its liquidity policy. The largest change, though, occurs with the switch to full allotment. Now primary market liquidity substitutes secondary market liquidity, raising the volumes at the standing facilities and reducing the

[23]Results are available on request from the author.

level of volumes in the interbank market. At the end of the maintenance period volumes at the deposit facility are lower and higher at the lending facility. Volumes in the Eonia market decrease, opposite to the period before, whereas there is no aggregate effect on GC Pooling volumes. Window dressing is still important in the unsecured and secured overnight interbank market.

Second, I study the impact of frictions on volumes in the interbank market and volumes at the the Eurosystem standing facilities, which form a fallback option to the interbank market. In the period before the collapse of Lehman Brothers, allocational inefficiencies due to frictions are present in the interbank market. Squeezing, however, does not materialize due to an accommodative liquidity provision by the Eurosystem. Credit risk plays a role in the unsecured market. Contrary to expectations, credit risk raises volumes in the Eonia market before Lehman, whereas a higher perceived riskiness of single banks decrease volumes. Banks shorten the maturities of their unsecured loans as a precaution to a rise in credit risk, whereas some banks are presumably completely excluded from trading in the Eonia market. This supports the notion of market segmentation. Volumes at the standing facilities and in GC Pooling increase when expected volatility in the stock market rises, implying first liquidity hoarding, and second the necessity for trading in an anonymous repo market. In the period after the introduction of full allotment, the use of the standing facilities is sensitive towards credit risk, whereas the unsecured segment of the interbank market shows no sensitivity towards any friction measure. Volume traded in GC Pooling rises when the uncertainty about a bank's default risk increases, implying that GC Pooling is a reliable hub for liquidity. After the start of full allotment, stock market volatility leads to a higher use of the lending facility. This implies that there are spillovers from other security markets to the interbank market. So despite the extensive liquidity supply by the Eurosystem, frictions persist, implying that without the intervention by the Eurosystem allocational inefficiencies would probably be huge.

As shown and also evidenced by Abbassi, Bräuning, Fecht, and Peydró (2014) the unsecured interbank market is alive after the collapse of Lehman and the switch to full allotment. Banks still trade unsecured. The unsecured market has the huge advantage of not requiring any infrastructure, whereas the overnight repo market needs a trading platform and securities serving as collateral. Completely replacing the unsecured market by the secured market or by Eurosystem monetary operations is not desirable. It is then either the Central Counterparty or the Eurosystem, who become the main counterparts in the interbank market, which reduces market discipline. The CCP and Eurosystem bear the credit risk of each bank. Even though, they have their risk mechanisms for credit risk in place, it creates other problems. If now one of the CCPs fails, this would be disastrous to the repo market. Instead, it is important that banks are fundamentally sound and there is sufficient transparency so that trust returns to the interbank market.

There are two routes to follow. On the one hand, the structure of the interbank market needs to be more robust, so that it allows banks to obtain liquidity when necessary. On the other hand, trading in the interbank market depends on the solvency of banks. If this risk does not decrease, banks will not be willing to trade with each other. CCPs help to make the interbank market more robust, but in this case the risk concentrates at the CCPs and banks have less incentive to monitor each other. The credible threat of losing access to liquidity should help to discipline banks. The question then remains how to deal with banks that have completely lost access to liquidity in the interbank market. The ECB determines the playing field, but it is not supposed to be the main actor. There are several possibilities to be the lender of last resort. The relative rate on the lending facility can be decreased. Instead of returning to a liquidity-neutral policy the Eurosystem may allocate more funds so that banks have a liquidity buffer if they want to.

3.7 Appendix

3.7.1 Trading in GC Pooling

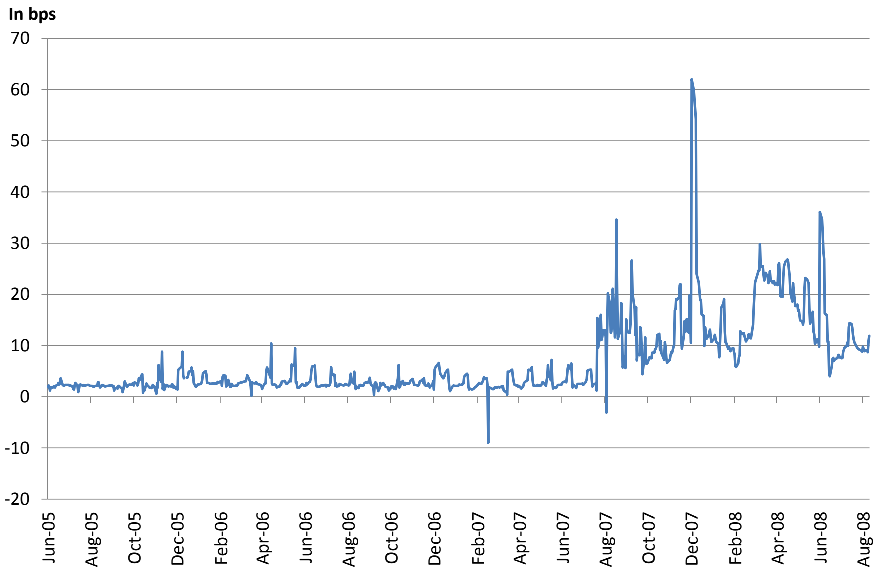
Repo transactions can be traded bilaterally over-the-counter (OTC), arranged by voice-brokers or by a triparty agent. The share of repos (Automated Trading Systems (ATS) and post-trade registration) cleared by a central counterparty (CCP) stands at 32.5% in June 2014, while the largest part of repo trading still consists of direct bilateral trading with 53.2% (ICMA, 2014).[24] One of the ATS that clears repo trades via a CCP is operated by Eurex Repo. In June 2014 Eurex Repo has 130 participants, out of which 115 trade in their main product GC Pooling.

Eurex Repo provides a quotebook for repo traders in which traders can enter their quotes. These quotes can consist of one or two repo rates and can only be entered in the pre-trading phase and during trading hours. Those quotes can be directly accepted by other traders which leads to the conclusion of a trade. Furthermore, one functionality of the system allows traders to signal their interest in a trade, which is called indication of interest. Other participants can react by sending an addressed offer, which may be accepted or rejected, thus leading to a trade or not. Quotes may also be accepted in part by a counterpart. The remaining quote size will stay in the quotebook. In an open repo, participants are able to set their own time span for the repo trade and they may exchange change rate requests. At the close of trading the remaining quotes in the quotebook are canceled. After the conclusion of a trade Eurex Clearing steps in as central counterparty. It nets all positions that a clearing member has entered during the day on the basis of the currency, the ISIN and settlement account. The GC baskets have their own ISIN, as e.g. the GC Pooling ECB basket. This reduces the margin requirement and Eurex Clearing only provides the net collateral or net cash position of all concluded trades to the counterparty. Thus, counterparty risk is effectively eliminated by the use of the CCP.

[24] Using average daily turnover instead of outstanding amount (ICMA), the Money Market Study by the ECB finds a percentage of 62%. CCP transactions normally have a short term, thus resulting in a relatively high turnover.

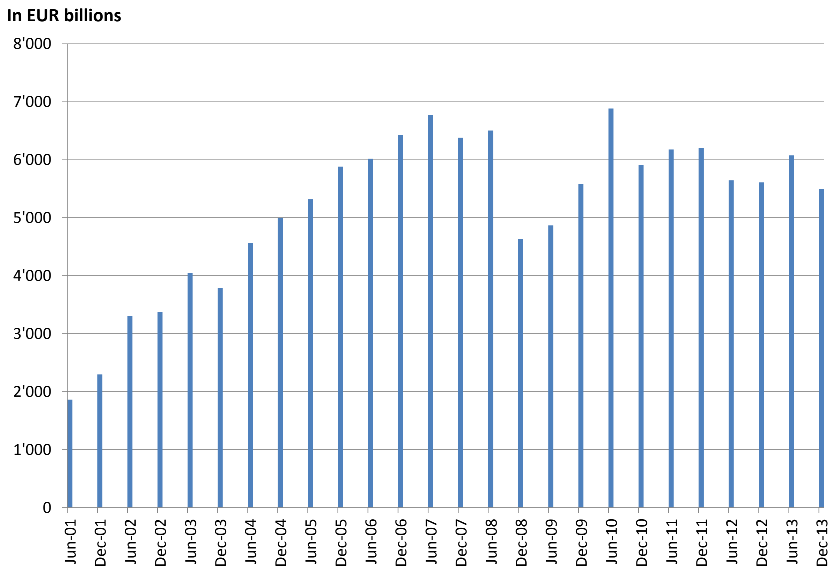
3.7.2 Figures

Figure 3.1: 1w Euribor - 1w EoniaSwap



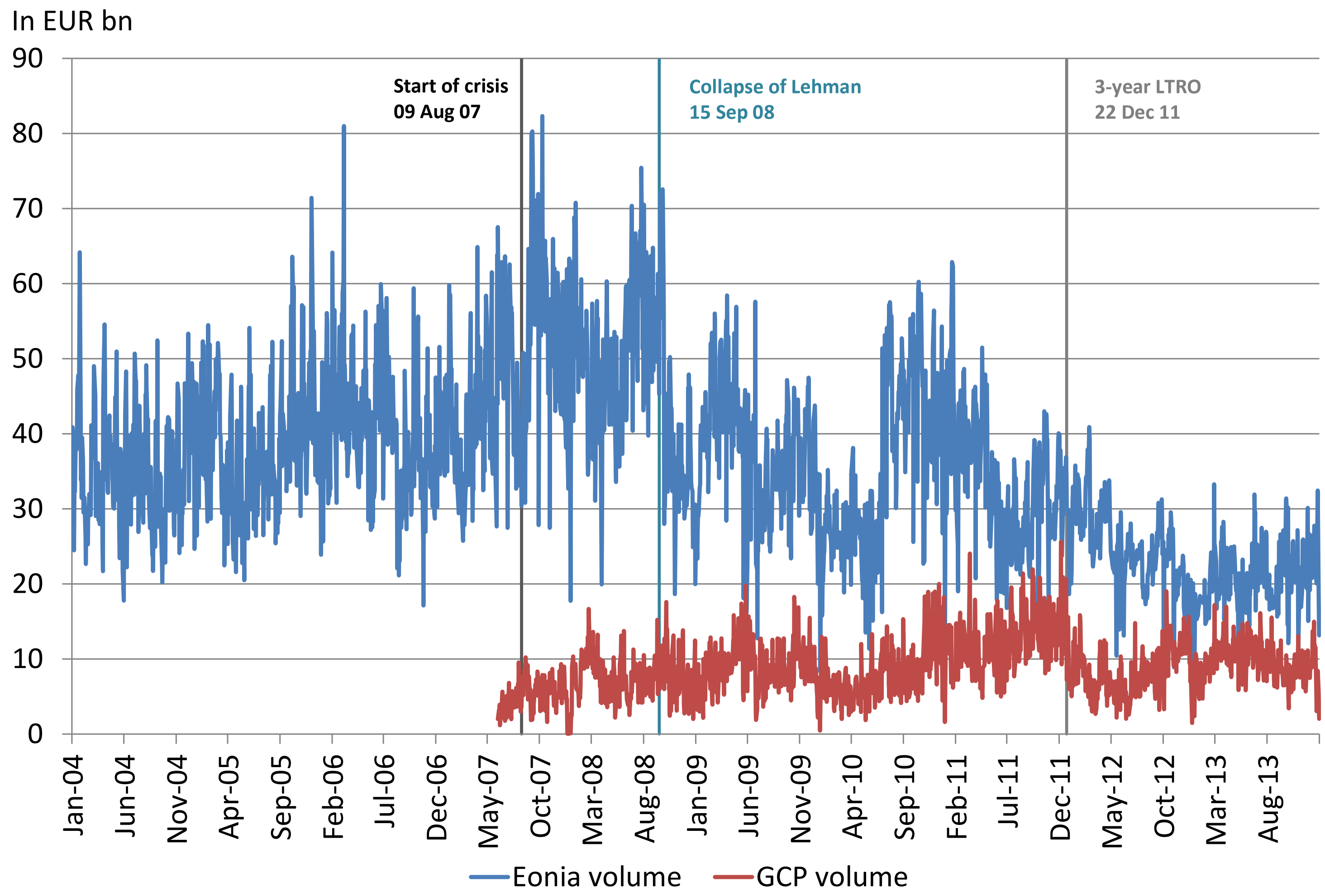
This graph shows the daily spread between the one-week Euribor and Eonia Swap (source: Euribor-EBF). The sample period is July 20, 2005 to August 30, 2008. The Euribor represents the unsecured rate, whereas the Eonia Swap is the OIS reference rate.

Figure 3.2: Outstanding repo volume in Europe



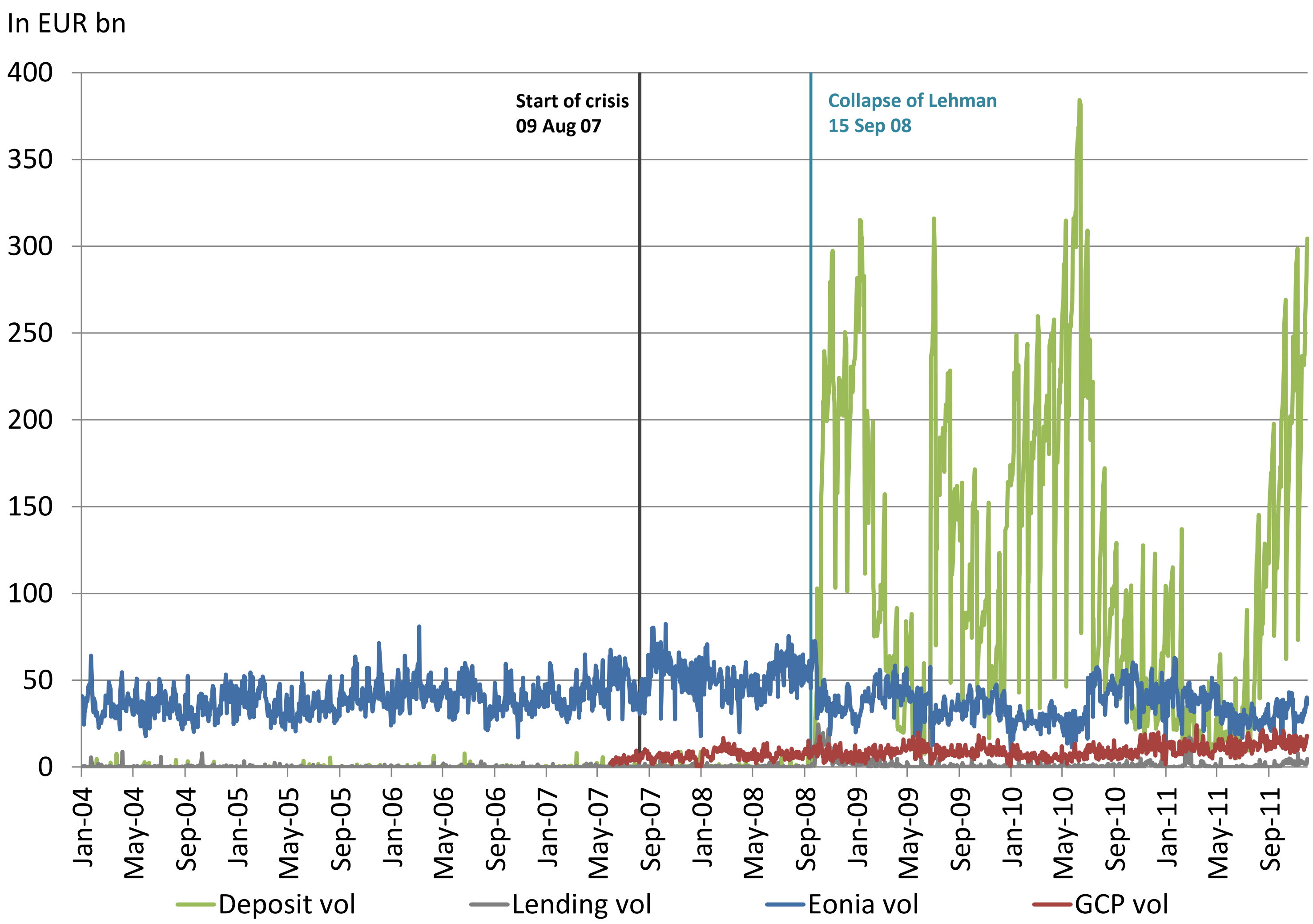
This graph displays the semi-annual outstanding repo volumes in Europe for the period June 2001 to December 2013 (source: ICMA). The largest contraction in this market can be noticed in December 2008, from which the market recovers subsequently.

Figure 3.3: Volumes in the interbank market



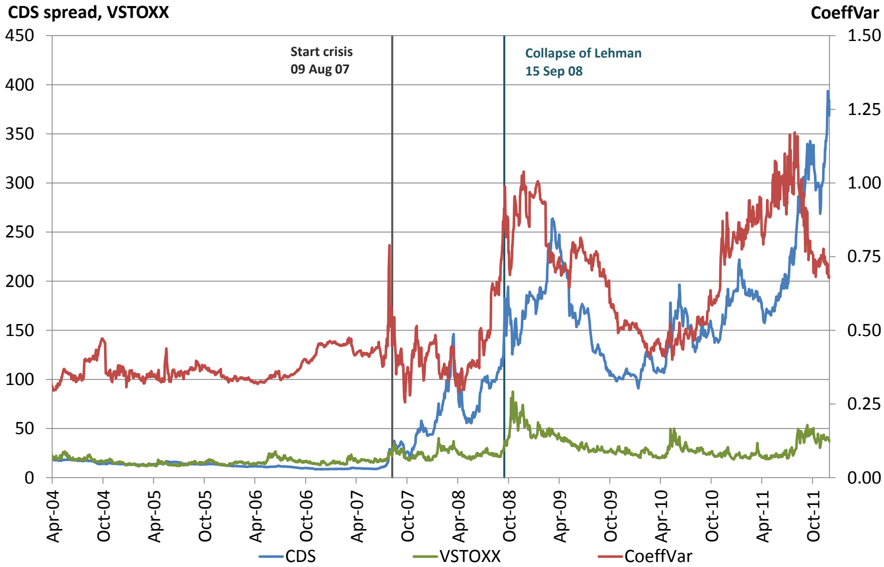
This graph shows the daily development of volumes in the Eonia, *Eonia volume*, and GC Pooling market, *GCP volume*, (source: ECB, Eurex Repo). The sample period is January 01, 2004 to December 31, 2013. The series of GC Pooling starts on June 01, 2007.

Figure 3.4: Volumes at the ECB and in the interbank market



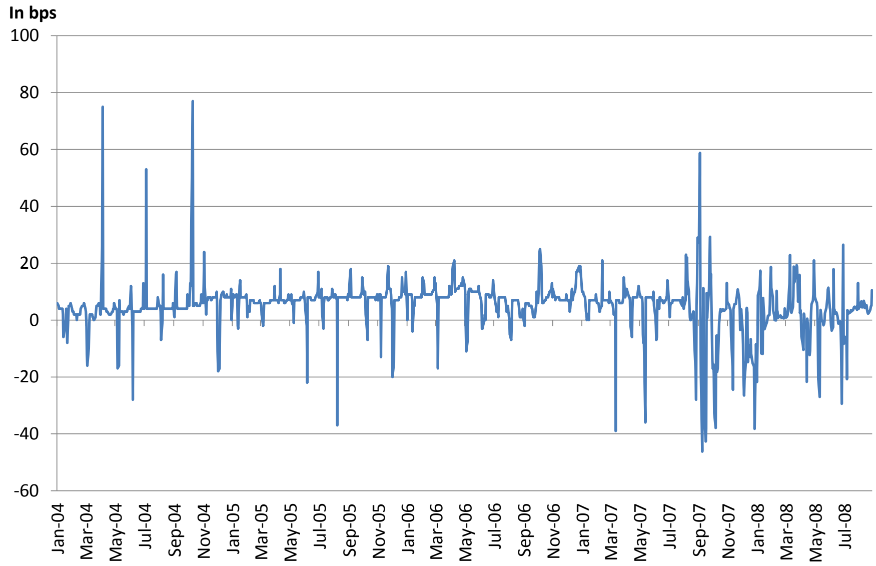
This graph shows the daily development of volumes at the ECB standing facilities and in the Eonia and GC Pooling market (source: ECB, Eurex Repo). *Deposit vol* and *Lending vol* display the series for the volumes at the deposit and the lending facility. *Eonia vol* and *GCP vol* represent the volumes in the Eonia and the GC Pooling market. The sample period is January 01, 2004 to November 30, 2011, the last day of the regression analysis.

Figure 3.5: Development of risk measures



This graph is based on daily data (source: ECB, Eurex Repo, Bloomberg). It shows the development of the risk measures for credit risk (*CDS*) of the combined Eonia and GC Pooling panel, uncertainty (*CoeffVar*) and expected volatility in the stock market (*VSTOXX*).

Figure 3.6: Eonia - MBR



This graph is based on daily data (source: ECB, Bloomberg). Eonia is the European Overnight Index Average, while the MBR is the ECB minimum bid rate in the weekly auction for liquidity, its policy rate. The spread displays several spikes, mainly occurring at the end-of-the-maintenance period, indicating that it is strongly influenced by the ECB institutional framework. The graph only covers the period until the bankruptcy of Lehman and the introduction of full allotment, because with start of full allotment the policy rate changes to the deposit facility rate.

3.7.3 Tables

Table 3.1: List of CDS banks

This list shows the banks trading in the Eonia market and/ or the GC Pooling market whose CDS spreads were used for calculating the average credit risk (*CDS*) and the coefficient of variation (*CoeffVar*). The composition of the panel stems from December 2009. The star designates if the bank belongs to both panels.

Eonia banks	GC Pooling banks
ABN Amro	Barclays*
Intesa	Bayerische Landesbank*
Bank of Ireland	BNP Paribas*
Barclays*	Commerzbank*
Bayerische Landesbank*	Credit Suisse
BBVA	Deutsche Bank*
BNP Paribas*	DZ Bank*
Santander	Fortis*
Bank of Tokyo	HSBC*
Calyon	HSH Nordbank
CGD	IKB
Citibank	JP Morgan
Commerzbank*	LBBW*
Dankse Bank	LB Hessen
Deutsche Bank*	Norddeutsche Landesbank*
Dexia	SEB
DZ Bank*	Unicredit*
Erste Bank	
Fortis*	
HSBC*	
ING	
Natixis	
JP Morgan	
KBC	
Caixa	
LBBW*	
MPS	
Norddeutsche Landesbank*	
Nordea	
Rabobank	
Raiffeisen Zentral	
Societe Generale	
Handelsbanken	
UBS	
Unicredit*	

Table 3.2: Descriptive Statistics

This table presents the descriptive statistics on the exogenous and endogenous variables. The first five lines: *Standing facilities*, *Deposit facility*, *Lending facility*, *Eonia volume* and *GC Pooling volume* denote the volumes in those segments. *Benchmark allotment* is the estimated liquidity neutral amount and *Deviation* denotes the difference between the benchmark allotment amount and the actual amount distributed. *Total outstanding liquidity* is the sum of the outstanding MRO and LTRO amount. *Bidding aggressiveness* is calculated as the difference between the weighted average bid rate in the auction and the one-week Eonia Swap rate at 8.30am. *CDS Comb* is the average CDS spread of all banks participating in the Eonia and/ or GC Pooling market, while *CDS Eonia* and *CDS GC Pooling* is the average CDS spread for the respective market. *CoeffVar* is the standard deviation across the respective panel divided by the average CDS level of the ten previous days.

Pre-Crisis (Mar 17, 2004 – Jun 30, 2007)

Panel A	No. Obs.	Median	St.dev.	Mean	St.error	Min.	Max.
Standing facilities (EUR mio.)	844	73	972.107	358.8	33.461	6	9386
Deposit facility (EUR mio.)	844	41	688.927	191.5	23.714	4	8066
Lending facility (EUR mio.)	844	11	576.077	167.3	19.829	0	8833
Eonia volume (EUR mio.)	844	38,153	8,783.4	39,039	302.34	17,133	80,996
GC Pooling volume (EUR mio.)	21	3,475	1,221.53	3,302	266.6	1,176	5640
Benchmark allotment (EUR mio.)	221	285,500	27,609	284,415	2,111	205,500	336,000
Deviation (EUR mio.)	221	500	1,069	760	81.76	-4,970	5,000
Total outstanding Liq. (EUR mio.)	844	398,000	46,404	387,000	1,597	280,000	46,000
Bid. aggressiveness (bps)	221	-1.0	1.638	-1.13	0.056	-5.8	10
CDS Comb (bps)	844	12.86	2.845	12.75	0.098	8.54	18.98
CDS Eonia (bps)	844	12.72	2.855	12.68	0.098	8.56	19.01
CDS GCP (bps)	844	14.60	2.793	14.4	0.096	10.00	20.90
CoeffVar Comb	844	0.357	0.044	0.372	0.001	0.295	0.475
CoeffVar Eonia	844	0.364	0.048	0.384	0.002	0.302	0.500
CoeffVar GCP	844	0.372	0.040	0.379	0.001	0.316	0.495
VSTOXX index (index points)	831	15.8	3.115	16.4	0.108	11.6	31.7

to be continued

Table 3.3: Descriptive Statistics cont.

First Stage Crisis (Aug 09, 2007 – Sep 12, 2008)

Panel B	No. Obs.	Median	St.dev.	Mean	St.error	Min.	Max.
Standing facilities (EUR mio.)	281	356	1,368	739	81.6	40	12,900
Deposit facility (EUR mio.)	281	264	1240.5	560	74	40	12,402
Lending facility (EUR mio.)	281	19	431.5	179	25.74	0	3,883
Eonia volume (EUR mio.)	281	51,472	10,101	51,753	602.6	17,748	82,340
GC Pooling volume (EUR mio.)	280	6,995	2,637	7,008	157.6	50	16,680
Benchmark allotment (EUR mio.)	57	158,000	55,386	157,471	7,336	-197,138	259,000
Deviation (EUR mio.)	57	18,000	35,358	25,100	4,683	3,000	217,000
Total outstanding Liq. (EUR mio.)	281	455,000	37,958	460,000	2,264	397,000	637,000
Bid. aggressiveness (bps)	57	15.5	6.89	16.2	0.41	0.0	31.5
CDS Comb (bps)	281	64.2	29.784	68.1	1.777	20.8	146.2
CDS Eonia (bps)	281	63.3	28.098	66.2	1.676	21.1	147.4
CDS GCP (bps)	281	60.6	27.48	65.2	1.639	20.3	130.8
CoeffVar Comb	281	0.402	0.108	0.431	0.006	0.256	0.870
CoeffVar Eonia	281	0.369	0.052	0.377	0.003	0.251	0.510
CoeffVar GCP	281	0.472	0.162	0.521	0.010	0.266	1.200
VSTOXX (index points)	275	23.9	4.1214	24.4	0.2485	17.2	40.2

FullAllotment (Oct 09, 2008 – Nov 30, 2011)

Panel C	No. Obs.	Median	St.dev.	Mean	St.error	Min.	Max.
Standing facilities (EUR mio.)	809	92,500	88,093	119,000	3,097	5,010	385,000
Deposit facility (EUR mio.)	809	91,541	87,713	117,110	3,083.8	4,981	384,260
Lending facility (EUR mio.)	809	243	3,067	1,401	107.8	0	28,707
Eonia volume (EUR mio.)	807	34,698	9,408	35,490	331.2	5,781	62,893
GC Pooling volume (EUR mio.)	807	8,984	3,870	9,564	136.2	453	24,055
Benchmark allotment (EUR mio.)	164	15,000	150,143	-988	11,724	-359,500	366,000
Deviation (EUR mio.)	164	141,000	127,409	157,000	9,949	-151,000	477,000
Total outstanding Liq. (EUR mio.)	809	647,000	124,132	633,000	4,364	407,000	896,000
CDS Comb (bps)	809	167.7	59.445	175.8	2.090	90.9	393.5
CDS Eonia (bps)	809	152.5	62.264	165.6	2.189	81.6	396.5
CDS GCP (bps)	809	144.8	42.278	154.5	1.486	95.4	314.4
CoeffVar Comb	809	0.740	0.186	0.721	0.007	0.400	1.172
CoeffVar Eonia	809	0.577	0.221	0.636	0.008	0.339	1.225
CoeffVar GCP	809	0.568	0.260	0.673	0.009	0.348	1.371
VSTOXX Index (index points)	776	27.9	11.547	32.2	0.415	18.5	87.5

Table 3.4: Calendar day effects - Pre-crisis period

This table is based on regressions with daily data and shows the empirical regularities in volumes that stem from the ECB operational framework and calendar day effects. The sample period is the pre-crisis period ranging from Mar 17, 2004 – Jun 30, 2007. The first column displays the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth the volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs. In terms of independent variables, the regression entails dummies for the weekdays *Monday*, *Tuesday*, *Wednesday*, and *Thursday*, their interaction terms with the last five days of the maintenance period *Endres*, the variable *Endres* itself, and a dummy for the last day of the quarter, *DumQtr*. Standard errors given in parentheses were corrected by using Newey-West with five lags (Greene, 2008). The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia
Weekdays				
Intercept	4.1811***	3.7188***	2.1900***	10.5267***
	(0.1057)	(0.095)	(0.1827)	(0.0211)
Monday	0.1680	-0.0819	0.6510***	-0.0292*
	(0.1321)	(0.1132)	(0.2447)	(0.0164)
Tuesday	0.0517	0.0564	0.2310	-0.0122
	(0.1238)	(0.1174)	(0.2188)	(0.0188)
Wednesday	0.0239	-0.0800	0.3550	-0.0299*
	(0.1240)	(0.1070)	(0.2212)	(0.0174)
Thursday	-0.0294	-0.2185**	0.2120	-0.0384***
	(0.1278)	(0.1039)	(0.2357)	(0.0167)
Interaction Terms				
Monday*Endres	0.9549***	0.8461***	1.4670***	0.0209
	(0.2551)	(0.2279)	(0.5354)	(0.0314)
Tuesday*Endres	2.4779***	1.9717***	3.5650***	0.0262
	(0.2850)	(0.2859)	(0.4992)	(0.0376)
Wednesday*Endres	-0.1742	-0.3052	0.3780	-0.1499***
	(0.2675)	(0.2420)	(0.4850)	(0.0374)
Thursday*Endres	-0.1704	-0.3706**	0.3660	-0.0685***
	(0.2681)	(0.1888)	(0.5455)	(0.0294)
Other factors				
Endres	0.7438***	0.8345***	0.2680	0.2341***
	(0.1930)	(0.1748)	(0.3692)	(0.0304)
DumQtr	2.4839***	1.7381***	3.3770***	-0.2160***
	(0.2505)	(0.4022)	(0.3461)	(0.0542)
No. Obs.	844	844	844	844
Adj. R^2	0.327	0.337	0.206	0.178
F-statistic	41.9	43.9	21.6	19.3

Table 3.5: Calendar day effects - First stage of the crisis

The table based on regressions with daily data shows the empirical regularities in volumes that stem from the ECB operational framework and calendar day effects. The sample period spans the dates Aug 09, 2007 – Sep 12, 2008. The first column displays the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth the volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs. In terms of independent variables, the regression entails dummies for the weekdays *Monday*, *Tuesday*, *Wednesday*, and *Thursday*, their interaction terms with the last five days of the maintenance period *Endres*, the variable *Endres* itself, and a dummy for the last day of the quarter, *DumQtr*. Standard errors given in parentheses were corrected by using Newey-West with five lags (Greene, 2008). The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Weekdays					
Intercept	5.6668***	5.3051***	2.6270***	10.8284***	8.8035***
	(0.1482)	(0.1648)	(0.3601)	(0.0266)	(0.0616)
Monday	0.3322***	0.1238	1.2200***	-0.0194	0.0273
	(0.1325)	(0.1278)	(0.4576)	(0.0269)	(0.0520)
Tuesday	0.0866	0.1743	0.5760	-0.0153	0.0131
	(0.1762)	(0.1443)	(0.4962)	(0.0270)	(0.0627)
Wednesday	-0.0621	-0.0099	0.1920	0.0165	-0.0279
	(0.1638)	(0.1270)	(0.4553)	(0.0315)	(0.0610)
Thursday	-0.1783	-0.0603	-0.1540	-0.0070	-0.0348
	(0.1451)	(0.0976)	(0.4380)	(0.0304)	(0.0703)
Interaction Terms					
Monday*Endres	0.1039	0.4016	-0.8150	0.0114	-0.0094
	(0.2796)	(0.2821)	(0.6734)	(0.0468)	(0.1075)
Tuesday*Endres	2.0363***	1.7600***	2.9530***	0.0886	0.2026
	(0.4811)	(0.4581)	(0.8644)	(0.0635)	(0.1249)
Wednesday*Endres	-0.3707	-0.3919	-0.4910	-0.0962	0.2297
	(0.2861)	(0.2867)	(0.9458)	(0.0630)	(0.1531)
Thursday*Endres	-0.023	-0.0384	-0.7320	-0.0875*	0.1952
	(0.269)	(0.2262)	(0.8979)	(0.0522)	(0.1348)
Other factors					
Endres	0.3759	0.5265	0.2580	0.1028*	-0.1051
	(0.3404)	(0.3236)	(0.7594)	(0.0568)	(0.1316)
DumQtr	2.4849***	2.7909***	0.8900	-0.6824***	-0.3300
	(0.3396)	(0.3596)	(1.4882)	(0.1529)	(0.2769)
Endyear					-3.1628***
					(0.2137)
No. Obs.	281	281	281	281	281
Adj. R^2	0.314	0.328	0.12	0.184	0.453
F-statistic	13.8	14.7	4.8	7.3	22

Table 3.6: Calendar day effects - Full Allotment

The table based on regressions with daily data shows the empirical regularities in volumes that stem from the ECB operational framework and calendar day effects. The sample period spans the dates Oct 09, 2008 – Nov 30, 2011. The first column displays the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth the volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs. In terms of independent variables, the regression entails dummies for the weekdays *Monday*, *Tuesday*, *Wednesday*, and *Thursday*, their interaction terms with the last five days of the maintenance period *Endres*, the variable *Endres* itself and a dummy for the last day of the quarter, *DumQtr*. *One-Year LTRO* is a dummy variable that takes the value of one in the period Jun 25, 2009 – Jul 01, 2010. Standard errors given in parentheses were corrected by using Newey-West with five lags (Greene, 2008). The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Weekdays					
Intercept	10.9921***	10.9644***	5.6115***	10.5142***	9.2414***
	(0.2154)	(0.2199)	(0.2892)	(0.0336)	-(0.0451)
Monday	0.0670***	0.0675***	0.3359***	0.0167	-0.0348
	(0.0206)	(0.0211)	(0.1523)	(0.0220)	(0.0380)
Tuesday	0.0621***	0.0611***	0.2199	0.0227	-0.0483
	(0.0261)	(0.0265)	(0.1660)	(0.0238)	(0.0414)
Wednesdays	-0.1698***	-0.1890***	0.1348	0.0319	-0.0693
	(0.0246)	(0.0298)	(0.2091)	(0.0238)	(0.0509)
Thursday	-0.1472***	-0.1496***	0.0237	0.0176	-0.1149***
	(0.0234)	(0.0234)	(0.1471)	(0.0215)	(0.0420)
Interaction Terms					
Monday*Endres	0.0353	0.0347	0.1443	-0.0540*	0.0535
	(0.0572)	(0.0575)	(0.3164)	(0.0318)	(0.0698)
Tuesday*Endres	-0.9204***	-0.9495***	1.5883***	-0.0869**	0.0052
	(0.1382)	(0.1415)	(0.4075)	(0.0438)	(0.0909)
Wednesday*Endres	-0.0154	-0.0016	0.1805	-0.0433	0.0917
	(0.0549)	(0.0587)	(0.3080)	(0.0328)	(0.0828)
Thursday*Endres	0.0212	0.0211	0.1362	-0.0370	0.0938
	(0.0420)	(0.0429)	(0.2329)	(0.0300)	(0.0757)
Other factors					
Endres	0.4997***	0.5136***	-0.5985	-0.0166	-0.0572
	(0.1363)	(0.1371)	(0.4001)	(0.0392)	(0.0603)
DumQtr	0.1787	0.1842	1.0501	-0.6931***	-0.4310**
	(0.2262)	(0.2290)	(0.5729)	(0.1524)	(0.1945)
One-Year LTRO	0.8523***	0.8763***	-0.8108***	-0.2145***	-0.3292***
	(0.2072)	(0.2088)	(0.2778)	(0.0420)	(0.0594)
No. Obs.	809	809	809	809	809
Adj. R^2	0.219	0.225	0.042	0.202	0.125
F-statistic	21.5	22.3	22	19.5	11.4

Table 3.7: Test for non-stationarity

The tests for non-stationarity are based on the Augmented Dickey-Fuller test. The null hypothesis is that the series tested is non-stationary. The superscripts $*$, $**$, and $***$ indicate significance at the 10%, 5% and 1% levels. Before Lehman refers to the period Mar 17, 2004 – Sep 12, 2008. Pre-Crisis is defined as the dates Mar 17, 2004 – Jun 30, 2007. First Stage spans the period Aug 09, 2007 – Sep 12, 2008 and Full Allotment refers to Oct 09, 2008 – Nov 30, 2011. *Deposit facility, Lending facility, Standing facilities, Eoniavol* and *GCP* denote the volumes at the deposit facility, lending facility, standing facilities, in the Eonia market and in the GC Pooling market. *Bidag*, bidding aggressiveness, is calculated as the difference between the weighted winning average bid rate in the auction and the one-week Eonia Swap rate at 8.30am. *TotLiq* denotes the sum of outstanding MRO and LTRO volumes. *CDScomb* is the average CDS spread of all banks participating in the Eonia and/ or GC Pooling market, while *CDSeon* and *CDSgcp* is the average CDS spread for the respective market. *Coeffcomb* is the standard deviation across the panel divided by the average CDS level of the ten previous days. *Coeffeon* and *Coeffgcp* is the same measure, only defined for the Eonia and GC Pooling panels. *VSTOXX* is the measure for volatility.

	Before Lehman	Pre-Crisis	First Stage	Full Allotment
Deposit facility	-4.971***	-8.101***	-4.291***	-3.764***
Lending facility	-12.91***	-12.12***	-11.34***	-6.192***
Standing facilities	-5.962***	-12.07***	-11.28***	-6.247***
Eoniavol	-5.415***	-8.556***	-4.311***	-5.176***
GCP	-5.748***	NA	-5.471***	-4.150***
Bidag	-1.991	-7.312***	-3.253**	NA
TotLiq	-2.546	-1.753	-5.471***	2.438
CDScomb	0.2313	-2.163	-0.8991	0.1861
CDSeon	-0.232	-2.142	-1.174	0.2604
CDSgcp	0.6497	-2.208	-0.7286	-0.2398
Coeffcomb	-0.4208	-2.527	-0.294	-1.800
Coeffeon	-3.188**	-2.373	-3.809***	-1.770
Coeffgcp	1.042	-3.081**	0.2696	-1.174
VSTOXX	-3.181**	-3.972***	-3.204**	-3.237**

Table 3.8: Frictions - Before Lehman

The table shows regressions based on weekly averages of volumes on the discussed measures of interbank market frictions for the period before Lehman (Mar 17, 2004 – Sep 12, 2008). The GC Pooling time series starts on 2007. Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs and demeaned. *Bidag* is the difference between the winning average bid rate in the auction and the one-week Eonia Swap rate, measuring the potential for squeezing. Δ *CDS* captures credit risk and $Res_{(\Delta CoeffVar|\Delta CDS)}$ the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CDS)}$ captures the expected volatility in the stock market. Both Δ *CoeffVar* and *VSTOXX* were both individually regressed in a first stage regression on Δ *CDS* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, Endyear*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *Endyear* the period 21 Dec 2007 - 31 Dec 2007. The regression containing autoregressive terms was estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.502***	-0.438***	-0.532***	-0.043	-0.274***
	(0.087)	(0.097)	(0.106)	(0.041)	(0.076)
y_{t-1}	0.167***	0.227***	0.020	0.671***	0.303**
	(0.067)	(0.069)	(0.066)	(0.067)	(0.144)
y_{t-2}	-0.117*	-0.013	-0.081	0.021	-0.206
	(0.068)	(0.069)	(0.065)	(0.086)	(0.127)
y_{t-3}	0.211***	0.135*	0.153***	0.049	-0.217*
	(0.068)	(0.071)	(0.065)	(0.080)	(0.128)
y_{t-4}	-0.024	0.050	0.044	0.077	0.299**
	(0.072)	(0.072)	(0.068)	(0.068)	(0.151)
y_{t-5}	0.141**				
	(0.066)				
Bidag_{t-1}	0.034***	0.048***	0.014	0.002	0.009*
	(0.010)	(0.012)	(0.013)	(0.003)	(0.005)
$\Delta\ \text{CDS}_{t-1}$	0.021	0.018	0.022	0.007***	0.019***
	(0.013)	(0.015)	(0.020)	(0.002)	(0.005)
$\text{Res}_{(\Delta\text{CoeffVar}\mid\Delta\text{CDS}),t-1}$	-0.341	-0.897	-3.533	-0.846***	-0.085
	(2.048)	(2.167)	(3.057)	(0.296)	(0.492)
$\text{Res}_{(\text{VSTOXX}\mid\Delta\text{CDS}),t-1}$	0.054***	0.058***	0.030	0.005	0.046***
	(0.017)	(0.021)	(0.024)	(0.004)	(0.009)
Endres_t	1.736***	1.658***	1.763***	0.165***	-0.147*
	(0.111)	(0.123)	(0.189)	(0.015)	(0.082)
DumQtr_t	1.375***	0.781***	1.706***	0.038	-0.243**
	(0.196)	(0.217)	(0.307)	(0.025)	(0.112)
Endyear_t					-0.558**
					(0.267)
No. Obs.	236	236	236	236	68
σ^2	0.607	0.709	1.490	0.0135	0.064
Loglikelihood	-274.9	-293.2	-380.5	172.2	-3.34

Table 3.9: Frictions - Full Allotment

The table shows regressions of volumes based on weekly averages on the discussed measures of interbank market frictions for the period after the start of full allotment (Oct 09, 2008 – Nov 30, 2011). Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs and demeaned. ΔLiq measures the change in outstanding liquidity, Δ *CDS* credit risk and $Res_{(\Delta CoeffVar|\Delta CDS)}$ the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CDS)}$ captures the expected volatility in the stock market. Both Δ *CoeffVar* and *VSTOXX* were both individually regressed in a first stage regression on Δ *CDS* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, One-Year LTRO*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *One-Year LTRO* the period 25 Jun 2009 – 01 Jul 2010. The regressions containing autoregressive terms were estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.129	-0.147	0.036	0.011	0.026
	(0.362)	(0.352)	(0.206)	(0.069)	(0.222)
y_{t-1}	0.998***	1.006***	0.348***	0.737***	0.369***
	(0.081)	(0.080)	(0.078)	(0.080)	(0.087)
y_{t-2}	-0.348***	-0.337***	0.067	-0.180*	0.202**
	(0.113)	(0.112)	(0.084)	(0.104)	(0.091)
y_{t-3}	0.194*	0.174	-0.093	0.158	0.131
	(0.115)	(0.114)	(0.084)	(0.101)	(0.094)
y_{t-4}	0.259**	0.301***	0.145*	0.134	0.140
	(0.115)	(0.115)	(0.079)	(0.087)	(0.086)
y_{t-5}	-0.179**	-0.220***			0.101
	(0.080)	(0.080)			(0.083)
Δ Liq_t	0.789**	0.747*	-0.231	-0.780***	-1.255***
	(0.399)	(0.389)	(1.870)	(0.174)	(0.313)
Δ CDS_{t-1}	0.005***	0.005***	0.014	0.001	0.002
	(0.002)	(0.002)	(0.010)	(0.001)	(0.002)
$\text{Res}_{(\Delta\text{CoeffVar}\|\Delta\text{CDS}),t-1}$	-0.913	-0.996*	0.200	-0.070	0.740*
	(0.608)	(0.592)	(2.487)	(0.261)	(0.421)
$\text{Res}_{(\text{VSTOXX}\|\Delta\text{CDS}),t-1}$	0.010	0.011	0.065***	0.003	0.005
	(0.011)	(0.010)	(0.015)	(0.003)	(0.004)
Endres_t	0.460***	0.463***	-0.063	-0.040*	-0.022
	(0.048)	(0.047)	(0.221)	(0.021)	(0.035)
DumQtr_t	0.139	0.138	0.321	-0.106***	-0.092
	(0.087)	(0.084)	(0.376)	(0.039)	(0.056)
One-Year LTRO_t	1.097***	1.124***	-0.125	0.040	-0.251**
	(0.261)	(0.256)	(0.455)	(0.088)	(0.118)
No. Obs.	164	164	164	164	164
σ^2	0.131	0.127	1.55	0.019	0.038
Loglikelihood	-67.01	-64.6	-269	93.12	35.17

Table 3.10: Frictions - Subperiods (before Lehman)

The table shows regressions of volumes based on weekly averages on the discussed measures of interbank market frictions for the pre-crisis period and the first stage of the crisis. The pre-crisis period ranges from Mar 17, 2004 – Jun 30, 2007. Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs and demeaned. *Bidag* is the difference between the winning average bid rate in the auction and the one-week Eonia Swap rate, measuring the potential for squeezing. Δ *CDS* captures credit risk and $Res_{(\Delta CoeffVar|\Delta CDS)}$ the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CDS)}$ captures the expected volatility in the stock market. Both Δ *CoeffVar* and *VSTOXX* were both individually regressed in a first stage regression on Δ *CDS* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, Endyear*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *Endyear* the period Dec 21, 2007 - Dec 31, 2007. The regression containing autoregressive terms was estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

Pre-Crisis	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.565***	-0.449***	-0.632***	-0.048	
	(0.102)	(0.106)	(0.119)	(0.034)	
y_{t-1}	0.166*	0.190***		0.621***	
	(0.077)	(0.080)		(0.078)	
y_{t-2}	-0.125	0.008		0.012	
	(0.082)	(0.082)		(0.099)	
y_{t-3}	0.224***	0.125		0.092	
	(0.080)	(0.082)		(0.094)	
y_{t-4}	-0.068	-0.024		0.022	
	(0.081)	(0.083)		(0.080)	
y_{t-5}	0.123				
	(0.079)				
Bidag_{t-1}	0.014	0.027	-0.028	-0.002	
	(0.039)	(0.040)	(0.056)	(0.005)	
$\Delta\ \text{CDS}_{t-1}$	0.049	0.288	-0.299	-0.035	
	(0.237)	(0.261)	(0.345)	(0.034)	
$\text{Res}_{(\Delta\text{CoeffVar}\|\Delta\text{CDS}),t-1}$	0.608	-3.128	-2.833	-0.971	
	(5.021)	(5.419)	(7.461)	(0.709)	
$\text{Res}_{(\text{VSTOXX}\|\Delta\text{CDS}),t-1}$	0.075***	0.066**	0.058*	0.000	
	(0.027)	(0.029)	(0.032)	(0.006)	
Endres_t	1.966***	1.817***	2.041***	0.193***	
	(0.137)	(0.147)	(0.234)	(0.017)	
DumQtr_t	1.462***	0.727***	1.887***	0.086***	
	(0.250)	(0.272)	(0.380)	(0.030)	
No. Obs.	172	172	172	172	
σ^2	0.680	0.767	1.61	0.013	
Loglikelihood	-211.0	-221.3	-284.9	130.1	

Table 3.11: Frictions - Subperiods (before Lehman) continued

The table shows regressions of volumes based on weekly averages on the discussed measures of interbank market frictions for the first stage of the crisis. The first stage crisis period ranges from Aug 09, 2007 – Sep 12, 2008. Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. Those volume measures, the dependent variables, are in logs and demeaned.*Bidag* is the difference between the winning average bid rate in the auction and the one-week Eonia Swap rate, measuring the potential for squeezing. Δ *CDS* captures credit risk and $Res_{(\Delta CoeffVar|\Delta CDS)}$ the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CDS)}$ captures the expected volatility in the stock market. Both Δ *CoeffVar* and *VSTOXX* were both individually regressed in a first stage regression on Δ *CDS* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, Endyear*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *Endyear* the period Dec 21, 2007 - Dec 31, 2007. The regression containing autoregressive terms was estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

First Stage Crisis	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.400***	-0.446***	-0.334**	-0.028	-0.042
	(0.118)	(0.161)	(0.156)	(0.051)	(0.105)
y_{t-1}	0.435***	0.447***	-0.189	0.640***	0.361***
	(0.131)	(0.128)	(0.140)	(0.142)	(0.144)
y_{t-2}				0.127	-0.378***
				(0.137)	(0.144)
Bidag_{t-1}	0.011	0.032	0.021	0.002	0.006
	(0.014)	(0.020)	(0.022)	(0.003)	(0.006)
$\Delta\ \text{CDS}_{t-1}$	0.013	0.017	0.011	0.004**	0.005
	(0.009)	(0.013)	(0.018)	(0.002)	(0.005)
$\text{Res}_{(\Delta\text{CoeffVar}\|\Delta\text{CDS}),t-1}$	-3.325**	-2.767	-7.886**	0.008	-0.007
	(1.574)	(2.105)	(3.637)	(0.367)	(0.595)
$\text{Res}_{(\text{VSTOXX}\|\Delta\text{CDS}),t-1}$	-0.028	-0.002	-0.045	0.003	0.041***
	(0.025)	(0.034)	(0.036)	(0.006)	(0.010)
Endres_t	1.271***	1.426***	0.919***	0.084***	-0.088
	(0.141)	(0.186)	(0.366)	(0.027)	(0.085)
DumQtr_t	1.320***	1.282***	1.309**	-0.083*	-0.361***
	(0.236)	(0.316)	(0.573)	(0.044)	(0.132)
Endyear_t					-0.597**
					(0.279)
No. Obs.	57	57	57	57	57
σ^2	0.223	0.399	1.090	0.009	0.069
Loglikelihood	-38.27	-54.77	-83.34	54.24	-4.78

Table 3.12: Interest rate spreads

The table displays weekly regressions of interest rate spreads on bidding aggressiveness (*Bidag*), the last week of the quarter (*DumQtr*), and the last week of the maintenance period *Endres* for the period before Lehman and subperiods. *Bidag* is defined as above. In the third and fourth columns (WLOP) the last week of the maintenance period was eliminated because spreads spike due to excess or deficit liquidity, which is not directly related to squeezing. The two interest rate spreads, the dependent variables, are Eonia-MBR and GCP-MBR, where MBR is the ECB minimum bid rate. The weekly average was calculated for these spreads. Before Lehman denotes the period Mar 17, 2004 – Aug 30, 2008. Pre-crisis is defined as Mar 17, 2004 – Jul 31, 2007, and first stage crisis by Aug 09, 2007 – Aug 30, 2008. Standard errors are corrected by Newey-West's method with lags being determined by the integer closest to the fourth root of the number of observations (Greene, 2008). The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Before Lehman		Before Lehman WLOP		Pre-Crisis (all obs)	First stage crisis (all obs)	
	Eonia-MBR	GCP-MBR	Eonia-MBR	GCP-MBR	Eonia-MBR	Eonia-MBR	GCP-MBR
Intercept	6.6485***	7.313***	6.670***	6.656***	6.866***	5.367**	7.836***
	(0.357)	(1.189)	(0.391)	(1.364)	(0.512)	(2.567)	(2.694)
Bidag_{t-1}	-0.309***	-0.169	-0.262***	-0.117	-0.033	-0.188	-0.201
	(0.073)	(0.115)	(0.074)	(0.126)	(0.176)	(0.185)	(0.191)
Endres_t	-2.831***	-3.360***			-2.476*	-5.764***	-3.151*
	(1.164)	(1.454)			(1.387)	(2.149)	(1.850)
DumQtr_t	3.712***	-0.503	1.901*	-0.755	4.317***	-1.589	-0.573
	(1.554)	(2.546)	(1.078)	(2.457)	(1.552)	(3.648)	(3.278)
No. Obs.	236	68	182	48	172	57	57
Adj. R-squared	0.222	0.028	0.166	0.000	0.104	0.073	0.005
F-statistic	23.3	1.63	19	0.415	7.61	2.46	1.1

Table 3.13: Liquidity acquisition

The table shows the regression of the change in the log of total outstanding liquidity (MRO+LTRO) on a change in credit risk, *CDS*, for the period following the switch to full allotment (09 Oct 2008 – 30 Nov 2011). Standard errors are corrected by Newey-West's method with lags being determined by the integer closest to the fourth root of the number of observations (Greene, 2008), resulting in four lags for each regression. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	ΔLiq	ΔLiq
Intercept	-0.0013	0.0013
	(0.0030)	(0.0036)
Δ CDS$_{t-1}$	0.0008***	0.0008***
	(0.0003)	(0.0003)
Res$_{(\Delta\text{CoeffVar}\mid\Delta\text{CDS}),t-1}$		-0.0278
		(0.0780)
Res$_{(\text{VSTOXX}\mid\Delta\text{CDS}),t-1}$		0.0003
		(0.0002)
Endres$_t$		-0.0098
		(0.0063)
DumQtr$_t$		-0.0336
		(0.0352)
One-Year LTRO$_t$		0.0109
		(0.0131)
No. Obs.	164	164
Adj. R^2	0.019	0.034

Table 3.14: Squeezing

The table displays regressions of indicators of squeezing on a weekly basis in the pre-crisis period (Mar 17, 2004 – Jun 30, 2007). *Bidag* is defined as above. *Deviation* is calculated as the difference between the allotted amount in the MRO auction and the announced benchmark allotment amount. Volumes at the deposit facility and in the Eonia market are analyzed as well as the spread Eonia–MBR. In all regressions I control for the last week of the quarter, *DumQtr*, and the maintenance period, *Endres*. In the Eonia-MBR regression the last week of the maintenance period is excluded. Standard errors are corrected by Newey-West's method with lags being determined by the integer closest to the fourth root of the number of observations (Greene (2008), p.643). The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

Pre-crisis period	Bidag	Deviation	Deposit facility	Eonia volume	Eonia-MBR (w/o last week)
Intercept	-1.355	1.149***	4.010	10.500***	5.833***
	(0.1209)	(0.167)	(0.136)	(0.0276)	(0.454)
Bidag_{t-1}		0.283***	0.013	-0.006	-0.263**
		(0.054)	(0.069)	(0.006)	(0.126)
Deviation_{t-1}			0.018	0.049***	1.195***
			(0.043)	(0.018)	(0.348)
Endres_t	0.563**	-0.402***	1.810***	0.221***	
	(0.283)	(0.137)	(0.139)	(0.019)	
DumQtr_t	2.131*	-0.048	0.741***	0.096***	1.993***
	(1.226)	(0.191)	(0.263)	(0.040)	(0.464)
No. Obs.	172	172	172	172	133
R-Squared	0.0998	0.233	0.399	0.297	0.281
F-statistic	10.5	18.3	29.4	19.1	18.2

Table 3.15: Frictions - Before Lehman - Interaction Term

The table shows regressions based on weekly averages of volumes on the discussed measures of interbank market frictions for the period before Lehman (Mar 17, 2004 – Sep 12, 2008). Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. Data on GC Pooling volumes are available from June 01, 2007. All volume measures, the dependent variables, are in logs and demeaned. *Bidag* is the difference between the winning average bid rate in the auction and the one-week Eonia Swap rate, measuring the potential for squeezing. Δ *CDS* captures credit risk and $Res_{(\Delta CoeffVar|\Delta CDS)}$ the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CDS)}$ captures the expected volatility in the stock market. Both Δ *CoeffVar* and *VSTOXX* were both individually regressed in a first stage regression on Δ *CDS* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, Endyear*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *Endyear* the period Dec 21, 2007 – Dec 31, 2007. *September* is a dummy variable for the month of September 2008. This is interacted with $Res_{(\Delta CoeffVar|\Delta CDS)}$, giving the term *IntactCoeffVarSep*. The regression containing autoregressive terms (not displayed here) was estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.506***	-0.440***	-0.539***	-0.043	-0.307***
	(0.088)	(0.098)	(0.107)	(0.041)	(0.063)
Bidag_{t-1}	0.033***	0.048***	0.014	0.002	0.010***
	(0.010)	(0.012)	(0.013)	(0.003)	(0.004)
$\Delta\ \text{CDS}_{t-1}$	0.020	0.018	0.021	0.007***	0.019***
	(0.013)	(0.015)	(0.020)	(0.002)	(0.005)
$\text{Res}_{(\Delta\text{CoeffVar}\|\Delta\text{CDS}),t-1}$	-0.196	-0.520	-3.904	-0.907***	-0.091
	(2.083)	(2.230)	(3.141)	(0.294)	(0.485)
$\text{IntactCoeffVarSep}_{t-1}$	-5.394	-9.519	6.654	5.907**	-0.975
	(12.292)	(12.668)	(19.183)	(2.937)	(2.420)
$\text{Res}_{(\text{VSTOXX}\|\Delta\text{CDS}),t-1}$	0.055***	0.060***	0.029	0.004	0.048***
	(0.018)	(0.021)	(0.024)	(0.004)	(0.008)
Endres_t	1.735***	1.654***	1.764***	0.169***	-0.136
	(0.111)	(0.122)	(0.188)	(0.015)	(0.083)
DumQtr_t	1.381***	0.795***	1.713***	0.038	-0.254**
	(0.196)	(0.217)	(0.306)	(0.024)	(0.111)
September_t	0.372	0.347	0.297	0.021	0.354*
	(0.586)	(0.660)	(0.859)	(0.108)	(0.195)
Endyear_t					-0.632**
					(0.273)
No. of AR terms	5	4	4	4	4
No. Obs.	236	236	236	236	68
σ^2	0.606	0.708	1.49	0.013	0.061
Loglikelihood	-274.7	-292.9	-380.2	174.2	-1.63

Table 3.16: Before Lehman - Conditioning on CoeffVar

The table shows regressions based on weekly averages of volumes on the discussed measures of interbank market frictions for the period before Lehman (Mar 17, 2004 – Jun 30, 2007). Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. The data on GC Pooling volumes starts on 01 June 2007. All volume measures are in logs and demeaned. *Bidag* is the difference between the winning average bid rate in the auction and the one-week Eonia Swap rate, measuring the potential for squeezing. $Res_{(CDS|\Delta CoeffVar)}$ captures credit risk and *CoeffVar* the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CoeffVar)}$ captures the expected volatility in the stock market. Both Δ *CDS* and *VSTOXX* were individually regressed in a first stage regression on Δ *CoeffVar* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, Endyear*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *Endyear* the period Dec 21, 2007 – Dec 31, 2007. The regression containing autoregressive terms was estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.502***	-0.438***	-0.532***	-0.043	-0.274***
	(0.087)	(0.097)	(0.106)	(0.041)	(0.076)
y_{t-1}	0.167***	0.227***	0.020	0.671***	0.303**
	(0.067)	(0.069)	(0.066)	(0.067)	(0.144)
y_{t-2}	-0.117*	-0.013	-0.081	0.021	-0.206
	(0.068)	(0.069)	(0.065)	(0.086)	(0.127)
y_{t-3}	0.211***	0.135*	0.153***	0.049	-0.217
	(0.068)	(0.071)	(0.065)	(0.080)	(0.128)
y_{t-4}	-0.024	0.050	0.044	0.077	0.299**
	(0.072)	(0.072)	(0.068)	(0.068)	(0.151)
y_{t-5}	0.141**				
	(0.066)				
Bidag_{t-1}	0.034***	0.048***	0.014	0.002	0.009*
	(0.010)	(0.012)	(0.013)	(0.003)	(0.005)
$\text{Res}_{(\Delta\text{CDS}\|\Delta\text{CoeffVar}),t-1}$	0.007	0.005	0.024	0.008***	0.007
	(0.015)	(0.017)	(0.022)	(0.002)	(0.006)
Δ CoeffVar_{t-1}	0.052	-0.615	-2.283	-0.363	0.418
	(1.818)	(1.921)	(2.805)	(0.253)	(0.416)
$\text{Res}_{(\text{VSTOXX}\|\Delta\text{CoeffVar}),t-1}$	0.054***	0.058***	0.030	0.005	0.046***
	(0.017)	(0.021)	(0.024)	(0.004)	(0.009)
Endres_t	1.736***	1.658**	1.763***	0.165***	-0.147*
	(0.111)	(0.123)	(0.189)	(0.015)	(0.082)
DumQtr_t	1.375***	0.781***	1.709***	0.038	-0.243***
	(0.196)	(0.217)	(0.307)	(0.025)	(0.112)
Endyear_t					-0.559**
					(0.267)
No. Obs.	236	236	236	236	68
σ^2	0.607	0.709	1.49	0.0135	0.0639
Loglikelihood	-274.9	-293.2	-380.5	172.2	-3.34

Table 3.17: Full Allotment - Conditioning on CoeffVar

The table shows regressions of volumes based on weekly averages on the discussed measures of interbank market frictions for the period after the start of full allotment (Oct 09, 2008 – Nov 30, 2011). Each column represents a separate regression, one for each volume measure. The first column involves the use of the standing facilities, the second and third the use of the deposit and lending facility, the fourth the volume traded overnight in the Eonia market and the fifth volume traded overnight in GC Pooling. All volume measures are in logs and demeaned. ΔLiq measures the change in outstanding liquidity, $Res_{(CDS|\Delta CoeffVar)}$ credit risk and *CoeffVar* the information about the riskiness of a single bank. $Res_{(VSTOXX|\Delta CoeffVar)}$ captures the expected volatility in the stock market. Both Δ *CDS* and *VSTOXX* were individually regressed in a first stage regression on Δ *CoeffVar* to single out their effect in this regression. Calendar dummies (*Endres, DumQtr, One-Year LTRO*) are included. *Endres* captures the last week of the maintenance period, *DumQtr* the last week of the quarter, and *One-Year LTRO* the period Jun 25, 2009 – Jul 01, 2010. The regressions containing autoregressive terms were estimated by means of full maximum likelihood. Standard errors are given in parentheses. The superscripts *, **, and *** indicate significance at the 10%, 5% and 1% levels.

	Standing fac.	Deposit fac.	Lending fac.	Eonia	GC Pooling
Intercept	-0.129	-0.147	0.036	0.011	0.026
	(0.362)	(0.352)	(0.206)	(0.069)	(0.222)
y_{t-1}	0.998***	1.006***	0.348***	0.737***	0.369***
	(0.081)	(0.080)	(0.078)	(0.080)	(0.087)
y_{t-2}	-0.348***	-0.337***	0.067	-0.180*	0.202**
	(0.113)	(0.112)	(0.084)	(0.104)	(0.091)
y_{t-3}	0.194*	0.174	-0.093	0.158	0.131
	(0.115)	(0.114)	(0.084)	(0.101)	(0.094)
y_{t-4}	0.259**	0.301***	0.145	0.134	0.140
	(0.115)	(0.115)	(0.079)	(0.087)	(0.086)
y_{t-5}	-0.179**	-0.220***			0.101
	(0.080)	(0.080)			(0.083)
Δ Liq_t	0.789**	0.747*	-0.231*	-0.780***	-1.255***
	(0.399)	(0.389)	(1.870)	(0.174)	(0.313)
$\text{Res}_{(\Delta\text{CDS}\|\Delta\text{CoeffVar}),t-1}$	0.004	0.004	0.002	0.001	0.000
	(0.003)	(0.003)	(0.011)	(0.001)	(0.002)
Δ CoeffVar_{t-1}	-0.791	-0.878*	-0.173	-0.002	0.921**
	(0.542)	(0.524)	(2.335)	(0.222)	(0.455)
$\text{Res}_{(\text{VSTOXX}\|\Delta\text{CoeffVar}),t-1}$	0.010	0.011	0.065***	0.003	0.005
	(0.011)	(0.010)	(0.015)	(0.003)	(0.004)
Endres_t	0.460***	0.463***	-0.063	-0.040*	-0.022
	(0.048)	(0.047)	(0.221)	(0.021)	(0.035)
DumQtr_t	0.139	0.138	0.321	-0.106***	-0.092
	(0.087)	(0.084)	(0.376)	(0.039)	(0.056)
One-Year LTRO_t	1.097***	1.124***	-0.125	0.040	-0.251**
	(0.261)	(0.256)	(0.455)	(0.088)	(0.118)
No. Obs.	164	164	164	164	164
σ^2	0.131	0.127	1.55	0.0187	0.0377
Loglikelihood	-67.01	-64.61	-268.6	93.12	35.17

Part III

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Part IV

Curriculum Vitae

Curriculum Vitae

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